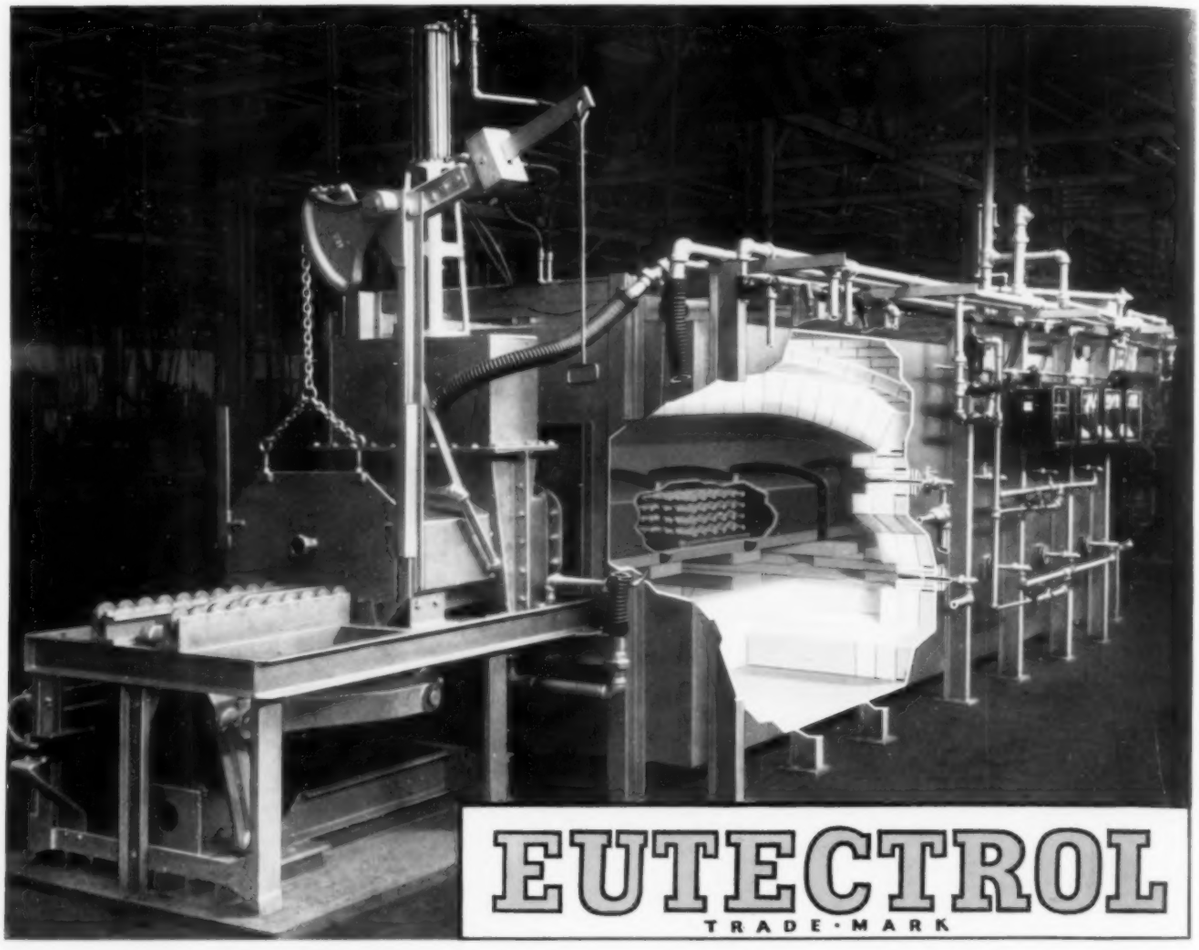

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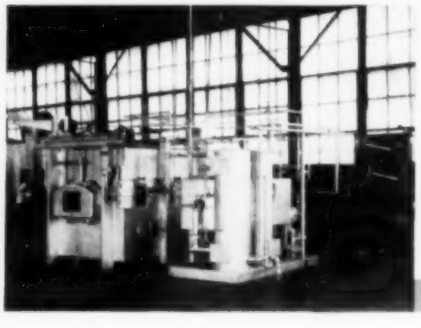

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METAL PROGRESS

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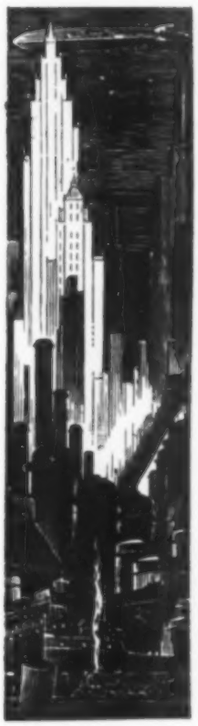

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GRAIN SIZE CONTROL

THE importance of grain size in alloy steel is recognized by the majority of gear manufacturers because of its far-reaching effect upon the fabrication and finished cost of their product. Grain size is a purely physical property and is controllable, within certain limits, according to the user's needs.

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Aluminum Additions in Modern Commercial Steels

Campbell Memorial Lecture
By H. W. McQuaid
Republic Steel Corp.

IN HIS introductory remarks H. W. McQuaid, who delivered the Edward DeMille Campbell Memorial Lecture at the Chicago convention of the Society, noted that the status of aluminum in steel metallurgy has completely changed within a few years. Users of the steel frowned upon it for they suspected it was only a means of doctoring second-grade heats. Despite this fact one brave steel maker was adding 1 lb. per ton to nickel-chromium heats as early as 1919 as a definite step to improve toughness. Likewise the lecturer and his associate, Eric Ehn, published comparative micros in 1922 showing the fine grain of heats killed with aluminum in comparison with similar heats killed with manganese and very coarse grained. Up to 3 lb. per ton was used in 1922 and 1923 in alloy steels, but its utility in controlling grain size was not emphasized by mill metallurgists — indeed, quite the contrary.

Meanwhile an enormous amount of work has been done by consumers in correlating grain size, analysis and heat treatment with desired properties like machinability, hardenability and toughness, and more exacting standards were continually being set. To meet these demands many investigations were made of every phase of steel making from scrap to finished product.

"Particular emphasis was put on deoxidation control," in the lecturer's words, "since it was soon learned that the most important factor in controlling the effect of the aluminum used was in the degree of oxidation and the type of oxides present when the deoxidizers were added. It is only natural that the electric steel maker should be able to control these effects before the open-hearth man could, and this advantage resulted in a considerable encroachment of electric steel in the field of basic open hearth. But the latter has developed the necessary technique, with the result that we are just emerging into a new understanding of its possibilities as a producer of high grade steels, equal in quality to any other method of producing commercial tonnage steels."

Some difference of opinion has arisen as to the specific effect of various chemical elements on grain size and response to quenching. In order to clear up some of these, the lecturer made several series of electric furnace heats, in each of which only one factor was allowed to vary. Data were presented to show that increasing aluminum is associated with finer microscopic grain size in the as rolled and normalized structure, and after carburizing at 1700, 1800 or 1900° F., and finer macroscopic grain size (Shepherd P-F test) after quenching from 1600 and 1700° F. Izod impact tests and Humphrey deflection values (to show ductility of carburized test pieces) vary as to hardness of the specimen and this is also definitely related to its grain size. McQuaid's conclusion is "All we can state is that apparently the aluminum bears a definite relation to the grain size in the heats in question, as well as to the hardenability, and whether the

hardenability characteristic is due directly to the fine grain or aluminum addition is difficult to determine, with our present knowledge."

Parallel experiments checked the widely-held understanding that manganese when used as a deoxidizer and residual alloying element is of relatively minor importance in grain size control. It does promote deep hardening (a contrary effect to aluminum's) but the low aluminum steels in McQuaid's series are coarse grained and normal and the high aluminum steels are fine grained abnormal no matter whether the manganese were high or low.

The steel consumer's knowledge of the importance of grain size control has been responsible for the reversion of opinion concerning aluminum as stated at the outset, for "variation in grain size is one of the most important factors, if not the most important, in determining variation in response to quenching, response to normalizing, and in inherent toughness which exists in commercial heats of steel in spite of close control of the usual chemistry. This variation in properties is of tremendous importance to the user of steel, and hence warrants our best efforts to determine the specific action of the aluminum addition, which is our main reliance today." (From now on the words are the lecturer's.)

Invisible Oxide Particles

It is generally assumed by the leading American metallurgists that the effect of aluminum is indirectly through submicroscopic particles of aluminum oxide which act as obstructing agents to grain growth and so produce the fine grained steels with all the accompanying characteristics. There are among us some, however, who do not entirely subscribe to this explanation of the effect of the aluminum addition.

It cannot be denied that submicroscopic dispersion of alumina particles would tend to inhibit grain growth, but some effects of aluminum additions do not satisfactorily line up with the theory. For instance:

If it is aluminum oxide, why does the *time* of making the addition play so important a part? In electric furnace steel which has already been completely deoxidized by ferromanganese and ferrosilicon additions (not to mention finishing under a reducing slag of very low FeO content) why is it so important that the aluminum addition be made within a very limited time before pouring?

In large open-hearth heats, why does the effect of the aluminum addition decrease rapidly near the end of the pour? If aluminum oxide in colloidal submicroscopic suspension is the primary cause of fine grain, grain growth control and hardenability control, why should the effect be so sensitive to time in the ladle? If this loss in effect is due to coalescence of the oxide particles, why, in the electric furnace, does fine grained scrap show a marked tendency to produce fine grained heats *without* aluminum (or with very small aluminum additions) when dead melted? And why, in the electric furnace, does the simple act of "boiling down" a heat of fine grained scrap eliminate this fine grained tendency in subsequent samples?

In American basic electric furnace practice where a so-called reducing slag is used under which to complete the oxidation, it has been found that the amount of aluminum required to obtain a certain definite grain size is less than in the basic open-hearth heats which are more highly oxidized. It might be argued that the same quantity and distribution of aluminum oxide should give the same grain size and that no extra aluminum would necessarily be required for the more highly oxidized heats unless a definite percentage of metallic aluminum in solution was required. If a critical amount or particle size of aluminum oxide is necessary, as would be expected, how could the act of increasing the aluminum above the minimum produce fine grain in over-oxidized heats? It seems rather doubtful whether the delicate control implied by the necessity of obtaining critical particle size and distribution could be obtained at all in the highly oxidized heats, or that increasing aluminum to a uniformly higher amount would produce the same critical dispersion of oxide particles in the more highly oxidized basic open-hearth heats that would be obtained in the electric furnace heat of similar composition but with a lower aluminum addition.

While it is difficult to prove, actual steel making practice indicates that a certain definite minimum of aluminum is needed before anything much happens, and beyond that amount the fine grain characteristics are obtained very rapidly. Thus, any melter will insist that fine or coarse grain specifications are not so difficult to meet, even in 100-ton heats, but that intermediate sizes are "commercially impossible." One of the unexpected characteristics of grain size control is this uniformity thoughout a large heat and to those of us who have checked thoroughly the grain size from the first molten steel in the fur-

nace to the final products, there is nothing more remarkable than the fact that under normal conditions of processing the variation in the McQuaid-Ehn grain size is almost commercially negligible.

It seems more logical to assume that more highly oxidized heats require the excess aluminum to satisfy the oxide present, and that the excess above that required to satisfy deoxidation requirements is necessary for grain growth control. This checks the common experience that the addition of ferromanganese and particularly ferrosilicon tends to reduce the amount of aluminum required to obtain the fine grain characteristics. It would appear that such additions of ferro-alloys reduce the amount of oxide present in the form of FeO, and would leave some aluminum over for solution in the iron, rather than promote the production of alumina particles of critical size dispersed uniformly throughout a large heat.

Let us now see how the theory (that it is metallic aluminum and its effect on the austenite transformation and carbide solubility that is the primary factor in grain growth variation and normality) fits the *time* element noted above. It can be argued that the loss of the aluminum effect in pouring open-hearth heats is due to the formation of aluminum oxide by oxidation under a slag of fairly high oxide content. In dead melted electric furnace heats, the oxidation may be insufficient to reduce the metallic aluminum content below that necessary to affect the grain size, so that the fine grained, dead melted charge may still remain fine grained when melted. Also on the other hand, the introduction of iron oxide in the form of ore to reduce the carbon would tend to reduce to a trace the metallic aluminum in the molten bath. It, of course, could be argued that the oxide particles would, in the case of the dead melted heat, be relatively unaffected whereas in the "boiled down" heat the physical action produced by the gas evolution or boil would result in coalescence of the oxide particles. Yet the fact that holding a fine grained, basic open-hearth heat for a relatively short time (as compared to finishing an electric heat) in the ladle will cause a loss of the aluminum effect indicates that the cause is probably not physical.

If now we are to assume that it is metallic aluminum remaining in the steel (in *addition* to that required to deoxidize) which is effective in obtaining that resistance to grain growth which is characteristic of so-called fine grained steel, we ought also to inquire into the connection between aluminum, hardenability and grain size.

The most important factor in the hardening of steel, as we know it today, is the carbon content, and we find as the carbon increases from zero to the eutectoid that it becomes easier to obtain higher and higher hardness by quenching. The fundamental requirement of hardening steel is to control the speed of quenching so that the rate of cooling through a limited range of temperature will be sufficiently high to completely suppress the pearlite transformation. This has been most clearly and thoroughly explained by Bain in the Campbell Memorial Lecture for 1932, and is cited to center our interest for the moment on the fundamental requirement in hardening steel. It is apparently necessary in order to obtain satisfactory results from a rapid cooling, that we start from a solution of carbon (or carbide) in austenite and cool this at the critical rate mentioned above. But prior to quenching, time at heat is required to obtain solution of the carbon or carbide in the austenite, and the time required varies not only with the carbide composition but also with the size and distribution of the carbide. Thus it is well known that spheroidized carbides are difficult to get into solution and a higher temperature and more time is required when the

Harry W. McQuaid

A graduate of Stevens Institute of Technology, 19 years on the staff of Timken Roller Bearing Co. and Timken-Detroit Axle Co., and now with Republic Steel Corp. He was the first to require controlled grain size in steel for its effect on hardenability.

"It is well to stress the fact that steel making is after all still an art in the hands of well trained men. They perform a modern miracle. Truly we cannot give too much credit to the man on the open-hearth floor."

carbon exists in rounded particles of cementite.

It is also well known that the solubility of carbon or carbide in austenite varies with the composition of the austenite and the form in which the carbon is present. Vanadium carbides are particularly difficult to get into solution and vanadium steels quenched directly from the carburizing temperature will almost invariably show the presence on the surface of an extremely high concentration of almost pure carbides. This indicates that at the carburizing temperature and under the conditions existing at the surface of the steel, these vanadium carbides were forming faster than the austenite absorbs the carbon from the carburizing agent. These steels can advantageously be carburized at temperatures 50 to 100° F. higher than ordinarily, in order to increase the solubility of carbon or carbide in the austenite. This higher temperature does not coarsen the steel, and it is an indication that the austenitic grain size established as we pass through the critical range will tend to be fixed by the presence of difficultly soluble carbides which exist at the grain boundaries in the saturated outer zone.

It also follows that the presence of any substance (such as aluminum) in the austenite which would tend to decrease the solubility of the carbon or carbide in the austenite would tend to favor the formation of excess carbides around the austenitic grain boundaries in the saturated zone at the lower carburizing temperatures. These carbide particles would tend to coalesce and become still more difficultly soluble and hence it is not at all impossible that under the usual conditions of carburizing we build up carbides in the boundaries of the saturated austenite grains at the lower carburizing temperatures which tend to restrict grain growth until we reach a temperature at which the solubility of carbon in the austenite has increased to the point where the carbide particles around the austenite grain boundaries will be absorbed.

Thus we are all familiar with the tendency in quenched, coarse grained chromium steels of the carburizing grade to exhibit, when fractured, a fine martensitic hyper-eutectoid zone and a coarse martensitic gradation zone, indicating the inhibiting action of the difficultly soluble chromium carbides in the hyper-eutectoid zone.

An indication of the effect of carbides which resist solution is found not only in vanadium steels, but also in most steels carburized in an active carburizer, since as a rule the hyper-eutectoid zone in a carburized piece resists grain growth to a higher temperature than the gradation zone or core. I have yet to see one plain carbon heat or vanadium steel heat where the core coarsened at a higher temperature than the case did.

In short the temperature and rate at which carbide particles are absorbed depends upon their size and composition and the presence in the austenite of some element which affects their solubility. Upon cooling, the reverse action takes place, and the final appearance of the separated ferrite and carbides depends on the temperature and speed at which the transformation occurs, which in turn has a pronounced effect on the mobility of the atoms.

If the transformation is at such a temperature and rate that the carbide not only has time to form plates but to coalesce further, the carbides will, in a hyper-eutectoid steel, coalesce on the boundary carbides those plates in contact with the boundary carbides, leaving the center of the pearlite grain lameller and forming the familiar abnormal rim. Temperature and speed of transformation on cooling are affected by several factors, among which are aluminum, iron oxide and iron sulphide in solid solution in the austenite.

The presence of manganese, nickel and similar elements that tend to stabilize the austenite would reduce the tendency to coalesce the carbide, due to the greater rigidity of the ferrite at the lower temperature of transformation. Thus the higher manganese steels would tend to be more normal than the lower manganese steels. For the same reason it is evident that any carburized steel having a hyper-eutectoid zone would, upon sufficiently slow cooling, develop an abnormal structure (as shown by Dr. Grossmann in his Campbell Memorial Lecture 1930). It is believed that this building up of the carbide plates which touch the boundary carbide, will be greater or less, depending upon the rate of rejection of the carbide from the ferrite and the rigidity of the ferrite. It is possible that aluminum in solution in the austenite increases the speed of carbide rejection and decreases the carbide solubility in the ferrite. At the same time it would increase the speed and temperature of the austenite transformation, a phenomenon which has been observed to be characteristic of the abnormal steel, and accounts for the more shallow hardening of this type of steel.

The greater tendency for the carbides to coalesce in steels to which aluminum has been added as evidenced by the abnormal structure, does not indicate at first glance the logical explanation of the relation of grain size to coalescence of the carbide. On heating, however, it is believed that the aluminum in solution in the austenite will delay the austenite transformation, and, due to the tendency of the carbides to exist in these steels in the more coalesced form, the carbides will be more difficult to dissolve. It is quite possible that there is a considerable tendency for the carbides in the steels containing aluminum to coalesce in the ferrite at temperatures just before the transformation to austenite. This would be the reverse phenomena from that met with in cooling and would develop carbides not only difficult to get into solution, but which would act as inhibitors to grain growth until a temperature had been reached in which they became readily soluble in the austenite.

Cause of Duplex Structure

Herty and his associates, studying silicon killed, plain carbon steels, find that the grain is not refined if heated through the transformation range faster than 90° F. per min.; the slower the heating rate the greater the grain refinement. Aluminum killed steels show strongly marked grain refinement regardless of heating rate. This important phenomenon can be explained by the increasing coalescence of the carbide in the ferrite of the silicon killed steel, which occurs with increase in time at the temperature of the transformation. With the aluminum killed steel, this sub-critical coalescence occurs even at the fastest rate of heating which is possible.

It should be remembered at this point that the austenite transformation rate, both on heating and cooling is affected by the presence of carbides, non-metallic inclusions and mechanical stresses, so that the grain growth inhibiting action of the carbides out of solution is also affected by these factors. Thus we may have in steels which are mechanically worked within the critical range, or just above the critical range, stresses in individual grains or groups of grains which facilitate the solution of carbides and thereby tend to form coarse grains in an otherwise fine grain structure. This produces the so-called duplex structure, directly connected with mechanical working. *(Continued on page 78)*

Remarkable in every way was the Convention and Exposition held last month in Chicago. As at a championship ball game, the reporter can only jot down his impressions of the high spots

17th Annual Convention

American Society for Metals

THOSE WHO ATTENDED the 17th Annual Convention in Chicago last month will look back upon it with a glow of pleasure. Many who were not so fortunate have already heard of this or that item of interest. The best that can be done in these few pages is to present a few glimpses of important events.

Conventions of the American Society for Metals are becoming increasingly complicated affairs. From the beginning they have improved on the annual gatherings of sister societies by adding an exposition of metals and metal treating equipment to the usual series of sessions devoted to the reading of technical papers. For several years one night has also been taken off for a banquet with its usual concomitants of stiff shirts, evening gowns and after-dinner ovations. Next the Campbell Memorial Lecture was instituted, and has formed a series of brilliant presentations, unapproached in quality. Other societies have joined with us in technical sessions to make it a veritable national metal congress, and of late years the serious-minded members have noted its similarity to a three-ring circus. Last year the experiment was tried of giving a series of lectures, somewhat elementary, covering an important part of the field; encouraged by its success there were two such lecture courses in Chicago — one afternoon, one evening.

Five lectures on the principles of heat treatment were given by M. A. Grossmann, director of research, Carnegie-Illinois Steel Corp. No less than 425 members attended one or more of these lectures; interest was so well sustained that one can safely predict that lectures of this sort will become a permanent fixture at the convention. Dr. Grossmann's text has been reprinted in an attractive volume.

E. J. Martin of the research division, General Motors Corp., discussed spectrographic analysis in three evening lectures. He used effectively an extensive series of models to explain certain aspects of the subject and also demonstrated the operation of principal types of equipment. This had been given as part of the educational series of the Detroit Chapter; however, attendance in Chicago averaged 160 persons.

Irvin Speaks at Banquet

THE AMERICAN SOCIETY FOR METALS was host to several hundred executives of the important steel producing companies in the Chicago district. Guests of honor were W. A. Irvin, president of United States Steel Corp., B. F. Fairless, president of Carnegie-Illinois Steel Corp., I. Lamont Hughes, executive vice-president, Carnegie-Illinois Steel Corp., and Walther Mathesius (trustee of the Society), operations manager, Carnegie-Illinois Steel Corp. Mr. Irvin gave the chief after-dinner address. Its main theme was an account of the recent advances in melting, rolling and treatment of high grade steel which have enabled the steel maker to meet the exacting demands of his customers. Indeed, as he emphasized, many of these advances could not have come about except by sympathetic cooperation

between producer and consumer. He also stressed the fact that no matter how extensive or intricate may be the labor-saving machines, men and men's brains will always be necessary first to make them and then to guide them.

President Irvin is better prepared by personal experience with these new forces in business to discourse in this vein than his predecessors in office or their contemporaries. Indeed, the best proof of the existence of a new era in the metallurgical industry is the very fact that such a speech *could* be made at such a time and before such an audience by the head of our largest steel corporation.

Society's Surplus Grows

REPORTS made at the annual meeting by officers of the national society were all glowing with present achievement and hopes for even greater things in the future. For example, Treasurer Gathmann showed that the operating profit of all society operations for the 12 months amounted to $11,500. This addition to surplus brings the total assets to $207,000, figured on the basis of securities at present market value. (About half are government bonds, at or above par.) Liquid assets of the chapters amount to another $50,000 in round numbers, making the total "worth" of the Society about $250,000.

New High in Membership

RECORD-BREAKING increase in membership rolls occupied much of Secretary Eisenman's report. Records show an unusual degree of stability. For instance, the impact of the stock market explosion, which is supposed to introduce the 1929 catastrophic depression, was not felt for some time, the membership of the Society gradually rising to its highest point (6339) in January of 1931. Even during 1931 the decline was moderate, the paid-up membership (there being no other kind in these records) being 5904 in January of 1932 and 5255 in January of 1933. A large number of members dropped out during the next five months, however, and the low spot of 3973 was reached in May of 1933.

That represented the turning point! Increases have been continuous ever since, month by month, with only one or two unimportant hesitations, and the previous high of January, 1931, was passed in 18 months at the beginning of 1935 — truly a remarkable recovery! Present total is 6880, with the best part of the year ahead, as the history of accessions proves.

The national secretary gave the greatest credit for this marvelous record to the enthusiasm of the individual members of the society. Many new members have been enrolled by reason of the educational courses held in a score of

Eye Appeal, Color, Motion, Characterized the Exposition, as Shown by This Typical View of an Exhibit Featuring Several "Dioramas" in the Background and a Continuous Movie at the Center. All photos by Kaufmann-Fabry.

cities, but they have been held and increased by the maintenance of interest through excellent programs at regular meetings of the chapters, and the publications and other services from headquarters. It was also his opinion that the change in name to American Society for Metals attracted the adherence of many worthwhile men who formerly felt that the scope of the society did not include their principal interest.

Economical Maximum

WHETHER OR NOT the point of diminishing returns is being reached has been a matter under consideration by the Board of Trustees. That the membership roll may be approaching an optimum figure is suggested by the fact that although the 1935 advertising income of METAL PROGRESS increased about 25% over 1934, the cost of additional editorial pages and a greatly enlarged circulation has absorbed all of that margin.

Zay Jeffries Honored

THE ALBERT SAUVEUR Achievement Medal, recognizing outstanding contributions to metallurgy, was awarded to Zay Jeffries, past president of the Society. He is one of the men we can point to when our friends overseas twit us with producing no pioneer thinkers. An appreciation of his personality and career will be reserved for a future issue, when space will permit some justice to the subject.

Exposition Highlights

"THIS EXPOSITION and congress should illustrate to everyone that metallurgy is a major factor in industrial life. More and more our designing engineers, sales managers and the general public realize that progress is a function, not of how fast we can make it, but of how long it will stand up, how much better it can be made, and how attractive and serviceable it can be. We are only on the threshold of developments to come."

In these words B. F. Shepherd, president of the Society, characterized the Chicago meeting. The exposition itself was most attractive and radiated cheerful optimism rather than the "fun first, business afterward" hullabaloo of pre-depression days. Some 230 firms participated, comparable in number and space with the 1928 show in Philadelphia and the 1929 show in Cleveland. Unexampled, however, was the attendance; about 17,000 executives, engineers and foremen registered their names and addresses. The total "gate" was slightly over 35,000, not counting attendance during the last evening, the only time the exposition was open to the general public.

Whether it is due to the influence of Chicago's Century of Progress, or merely to the continued trend toward color and finish, the exposition also set a new high in eye appeal. To single out individual showings would be invidious, since dozens of booths were arranged and decorated in a way that would have taken first prize only a few years back. One might venture the assertion that as a group the steel manufacturers' showings were outstanding. Many, many other exhibitors attracted attention by equipment in operation or some type of movement in the display — as of course was very desirable with so much compe-

Reid L. Kenyon

Trustee-Elect. Chemical Engineer from Purdue University. With American Rolling Mill Co., Middletown, Ohio, since 1920; now Supervising Research Engineer. His present problem is the development of wrought steel wheels. Active in Cincinnati Chapter (Chairman in 1932). Co-recipient of American Iron & Steel Institute's Medal for 1934.

ition for the visitor's attention. The three selections illustrated in these pages, therefore, represent ability to secure a good camera location rather than any appraisal of relative merit.

Seventeen Years Ago

THE SOCIETY'S first Steel Show was held in the Seventh Regiment Armory, in Chicago, 17 years ago. Another statistic for the statistic hounds: Last month was the fourth time the National Metal Exposition has been held in Chicago.

A Brief Acceptance Speech

THE MULTITUDE at the banquet applauded vigorously when Harry McQuaid was given a scroll which in future years will remind him of the trouble and worry involved in preparing a Campbell Memorial Lecture. A cynic was overheard to remark that the applause was chiefly on account of his speech of acknowledgment — he smilingly said "Thank you!"

As a matter of fact, no one anticipated a speech, for he had delivered it during the morning to an overflow audience. It reminded this reporter, however, of an occasion when exactly the same words were used to the huge disappointment of an expectant throng. It was at a testimonial dinner given some years ago in New York to Madame Curie, discoverer of radium. All the eminent physicists, chemists and physicians in the metropolitan region were there, not to mention a few mere bankers and businessmen. After a Waldorf-Astorian meal, one after another of the savants at the speakers' table lauded the guest of honor and told of the profound influence of the discoveries she and her husband had made. Finally came the long-awaited climax when the toastmaster introduced the little graying lady, and the diners sat back for the real treat of the evening. She timidly glanced to right and left, said an almost inaudible "Thank you" and sat!

Sam C. Spalding

Trustee-Elect. Mechanical Engineer from Columbia University. Has been assistant metallurgist for American Brass Co. Waterbury, Conn. since 1930. Previously with Remington Arms and Halcomb Steel Co. Past Chairman of both Syracuse and New Haven Chapters, A.S.M., and frequent speaker at conventions.

Award of Howe Medal

NO WORDS AT ALL were used at the banquet after T. D. Yensen and N. A. Ziegler were given the Henry Marion Howe Medal for the best paper in *Transactions* for the preceding year. They bowed and Mr. Yensen shook Mr. Ziegler's hand and Mr. Ziegler shook Mr. Yensen's hand in congratulation! Their paper appeared in June.

Cleveland Loses Brass Bell

THE PRESIDENT'S BELL, awarded each year to that chapter which in the opinion of the President has made a superior record, was transferred this year from Cleveland (which has held it for two years) to Chicago. In the words of President Shepherd, the award was made "for increasing its prestige in one of our large metal-working centers, and for its outstanding record in the number, variety and attendance at its educational courses."

Chicago, on Sept. 18, 1918, witnessed the birth of the American Steel Treaters Society, one of the organizations which merged into the present American Society for Metals. The first issue of its *Journal*, dated that same month, had an editorial emphasizing that many desirable ends

could be achieved by education, the prime object of the Society. It is worthy of special note that this ideal has been carried forward so clearly in the intervening years that the President cited it as a prime reason for choosing it from among many worthy contenders for his prize.

Nitrogen in Chromium Steels

Two phases of the very important and complex field of high chromium-iron alloys were discussed in one of the technical sessions. First was the effect of nitrogen in all types of chromium steels and second was the cause of embrittlement in 5% chromium tubing.

It will be recalled that Dr. Krivobok's Campbell Memorial Lecture in 1934 showed a striking parallelism between the action of nitrogen and carbon in chromium-iron alloys; the nitrides will go into solid solution on heating and precipitate out on cooling and tempering. Russell Franks, research metallurgist, Union Carbide & Carbon Research Laboratories, now supplements his earlier work on the same subject with a paper showing that these nitrides up to say 0.10% N enhance the hardening capacity of the 12 to 14% chromium steels (carbon about 0.07%). Properly quenched, these forged steels will have Brinell of 400 and ultimate strength of 195,000 psi., and when drawn back to half the hardness will have Izod impacts of 80 ft-lb. 0.08 to 0.16 nitrogen in the 16 to 18% chromium-iron alloys (carbon under 0.10) produces enough austenite to enable them to be heat treated and thus refine the grain of the otherwise ferritic structure. Brinell hardness of 175, ultimate strength of 100,000 psi., and Izod impact of 60 ft-lb. indicate what can be achieved in a class of chromium-irons which has in some quarters a reputation for brittleness.

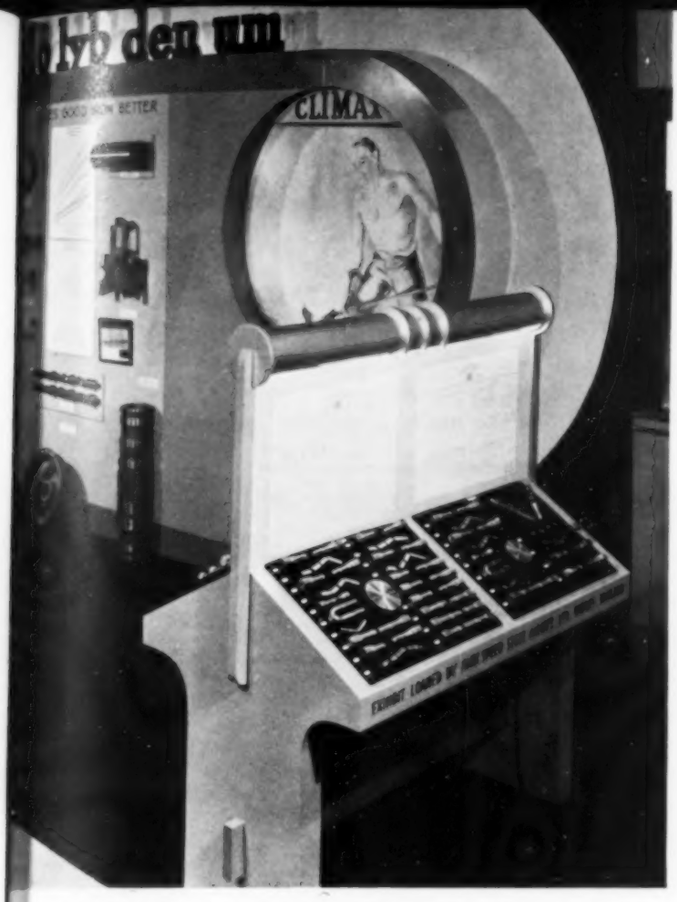
As pointed out by H. D. Newell, chief metallurgist of Babcock & Wilcox Tube Co., the benefits of grain refining by nitrides are especially noticeable in cold drawing operations. Dr. Krivobok also testified that nitrogen was far less harmful than carbon to the corrosion resistance of these steels in boiling 65% HNO_3; a tenfold increase in carbon (from 0.02 to 0.20) increased the penetration tenfold (from 0.003 to 0.036 in. per month), whereas a 20-fold increase in nitrogen only doubled the penetration.

Mr. Franks also thoroughly demonstrated the influence of 0.15 to 0.25% nitrogen in producing tough, fine grained steels containing 20 to 25% chromium and 0.15 to 0.20% carbon. These are remarkably resistant to grain growth after several days' stay at say 2000° F. E. C. Wright, metallurgist, National Tube Co., said that his firm had made a number of coils of seamless pipe of analysis near the top side of this analysis.

Ingots and billets could be forged with a wide range of finishing temperatures without developing coarse grained, brittle structures. The coils mentioned were fabricated by welding mill lengths of tube end to end. None of the welds developed coarsened structures adjacent to the joint, and all had good ductility and tensile strength. These tubes have given satisfactory service when operating up to 2000° F.

Obviously the optimum properties in these nitrogen alloys can only be achieved by proper processing and heat treatment. One prime difference between nitrogen and carbon is that an excess of the former will produce gas cavities in ingots and castings, whereas a proper amount will refine the grain.

Various Working Exhibits Showing Tool Steels, Tool Alloys and Carbides, and Grinding Wheels and Grinders Were Centers of Interest



...ation in the Modern Manner Makes Effective Display Background

Cooperating Societies

UNFORTUNATELY nothing more than merest mention of the interesting meetings of cooperating societies can find space. American Welding Society had, among other sessions, three round table discussions on Methods of Minimizing Distortion, Low Alloy Steels for Welding Purposes, and Fundamental Research in Welding.

Both the Institute of Metals Division and the Iron and Steel Division of the American Institute of Mining & Metallurgical Engineers joined in presenting H. C. Urey, Nobel prizeman and discoverer of "heavy hydrogen," in a lecture on Recent Developments in Isotopic Chemistry — brilliantly presented so that even metallurgists could understand some parts of it. An all-day discussion about methods for measuring temperature of liquid steel was another feature.

A notable event in the Wire Association was the presentation of its medal to B. L. McCarthy of Wickwire-Spencer Steel Co. — a prominent member of the American Society for Metals, Buffalo Chapter, and occasional contributor to METAL PROGRESS. (It seems to be a habit; last year another ASMember, E. J. P. Fisher, then of Keystone Steel & Wire Co., Peoria, took the coveted prize.)

Brittle 5% Cr Steels

DEMAND for a material considerably more corrosion resistant than carbon steel yet not as expensive as 18-8 stainless steel has led to the installation of many thousands of tons of 4 to 6% chromium steel tubes in petroleum stills. After about three years' service at 1100 to 1200° F., numerous failures occurred during winter shutdowns. Tensile properties of these tubes were unimpaired, and their toughness at 200° F. and higher was excellent, but at winter and sub-zero temperatures some of them became so brittle as to break when the coke was being cleaned out of them, the fractures being clearly intercrystalline. Carbon was 0.10 to 0.20%, and no changes could be found in the microstructure.

H. M. Wilten, metallurgical department, The Texas Co., presented an extensive study of such tubes. As a result he is inclined to the use of the "susceptibility to temper brittleness" as a criterion for selecting alloys for service at high temperature and pressure. This test, of English origin, is made by hardening impact specimens from 1650°, then tempering at 1200. Part of the samples are quenched from the draw, others are furnace cooled. The "susceptibility" is the ratio of impact strengths of quenched versus furnace cooled specimens. Mr. Wilten finds that new 4 to 6% chromium tubes had a susceptibility ratio of 2 to 9 and a number of brittle fractures occurred when cleaning after long service. On the other hand, plain carbon still tubes, and 4 to 6% chromium tubes to which 0.50% molybdenum had been added had a susceptibility ratio near unity — that is to say, were not temper brittle — and did not develop brittle fractures in service or during shut downs (a fact vouched for by H. D. Newell, chief metallurgist, Babcock & Wilcox Tube Co., the originator of this alloy.)

Discussion of this paper was along many lines. The impact test itself was questioned as a criterion, since the results depend too much on the type of notch (Izod Vee notch condemning "susceptible" steel when Charpy keyhole notch showed no brittleness) and on the temperature of test — all the above steels being "non-susceptible" at 200° F. and all being "susceptible" (at least in some tests) at sub-zero. Mr. Newell said that the mere flattening of a ring cut from a tube gives quite good enough indications for manufacturing control.

Furthermore, V. T. Malcolm, director of research, Chapman Valve Mfg. Co., *(See page 76)*

The New President of the Society

Robert S. Archer

An appreciation by one, a close associate for many years

ROBERT SAMUEL ARCHER, incoming President of American Society for Metals, has crowded a wealth of metallurgical experience into his two score years. His principal interests have been in aluminum and steel, but he has made important contributions in other fields, notably in copper and heat resisting alloys. His versatility is reflected in his attainments as author, inventor, executive and lecturer.

He was born June 20, 1895, near Denver, Colo. After finishing Cass Technical High School in Detroit, he attended the University of Michigan and received the degree of Bachelor of Chemical Engineering in 1916. A year later he received his Master's degree in Science. Fortune smiled on his student days and gave him the rare opportunity of serving as assistant to the late Prof. Edward DeMille Campbell, whose memory is honored each year in a lecture before the Society. At a critical time in his own life, as well as at a crucial period in the history of metallurgical science, his seeing eyes substituted for blinded ones, and brought the then current technical literature to Professor Campbell's eager and analytical brain. Together they discussed various experiments and theories which lead to a profound study of the earlier metallurgical literature.

When he left the University he served in the metallurgical department of the Bureau of Aircraft Production in Detroit until some time after the Armistice. Here his work had to do with specifications and inspection of various parts of the Liberty engine. In February, 1919, he began his aluminum work in Cleveland. It was characteristic of him to associate himself immediately with the activities of the Society (then called the American Steel Treaters Society) and we find his first contribution to its *Journal* in the form of an outline prepared for topical discussion on the annealing of castings in May, 1919.

From 1925 to 1930 he was head of the Cleveland Section of the Aluminum Research Laboratories. During the eleven years he was associated with Aluminum Co. of America, he became widely known as an authority on aluminum alloys and a leader in metallurgical thought. They were fruitful years in many respects. Numerous patents were issued to him and co-patentees on aluminum casting alloys and methods of casting, and heat treatable alloys, both cast and wrought. These include the important aluminum-silicon alloys for die casting and 25-S, 51-S and "super-duralumin" for rolled and extruded shapes. His high standing in that organization may be judged from the fact that one-third of the main volume of "The Aluminum Industry," prepared by experts on the staff of Aluminum Co. of America, is from his pen.

[That his mind was able to assimilate and correlate facts from all branches of physics, chemistry and metallurgy is evident from his work as co-author with Zay Jeffries of "The Science of Metals," published in 1924, a book which contains such stimulating generalizations as the slip interference theory of the hardening of metals. His work with aluminum gave him early familiarity with such phenomena as age hardening, only recently being recognized as a powerful factor in determining the properties of iron, copper, nickel and rarer metal alloys — EDITOR.]

In 1930 he moved to Milwaukee to become Director of Metallurgy for the A. O. Smith Corp. Here his metallurgical activities were both broad and intense, but were hampered, unhappily, by the industrial paralysis in the intervening years. Since 1934 he has been with the Republic Steel Corp. as Chief Metallurgist for the Chicago district, where his work relates essentially to production metallurgy — thus again strikingly illustrating his broad knowledge and versatility.

One of the great services which Mr. Archer has given to the profession has been the development of the data sheets on non-ferrous metals for the National Metals Handbook. As chairman of the Committee on Data Sheets of the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers, he directed the preparation of material comprising 144 pages of condensed and valuable information for the 1933 edition of this handbook. Other data sheets have been prepared but not yet published. This work will always stand as a monument to him and as a splendid example of the benefits from the cooperation of two great societies.

In the American Society for Metals, he has served as Chairman of the Cleveland Chapter and as a member of the Recommended Practice Committee. He has contributed generously to the pages of the *Transactions* and has given many notable talks to Chapters. He is in constant demand as a speaker. Two years ago he was elected to membership on the Executive Committee and last year be became Vice-President.

With confidence that the able leadership which has characterized his many activities will play an important rôle in the steady and rapid march of progress of the American Society for Metals, the membership welcomes its new President, Robert Samuel Archer.

ZAY JEFFRIES

Professor Moore writes, "I wish there were an effective way in which credit could be given to each of the score or more persons who have furnished the different plans for tests, designs of apparatus, and ways of stating results which I have 'Edited' into the text of the A. R. E. A. Bulletin No. 376 from which this is taken."

Internal Fissures in Railroad Rails

RAIL BREAKAGE is a problem as old as the railroad, and has attracted the attention of pioneer investigators of the strength of materials in all civilized countries. The first recognition of a type of fracture, starting from a spot in the *interior* of a rail head and growing to dangerous proportions while entirely concealed below the surface — in short, the internal transverse fissure — followed an investigation of a disastrous wreck in 1911 made by the late James E. Howard.

Since that time a large amount of study has been given to this phenomenon of internal fissures. The American Railway Engineering Association has collected statistics for about 20 years, classifying fissured rails as to manufacturer, section and age in track. Based on these figures and on independent investigations — some rather extensive — a variety of theories have been deduced as to their fundamental cause.

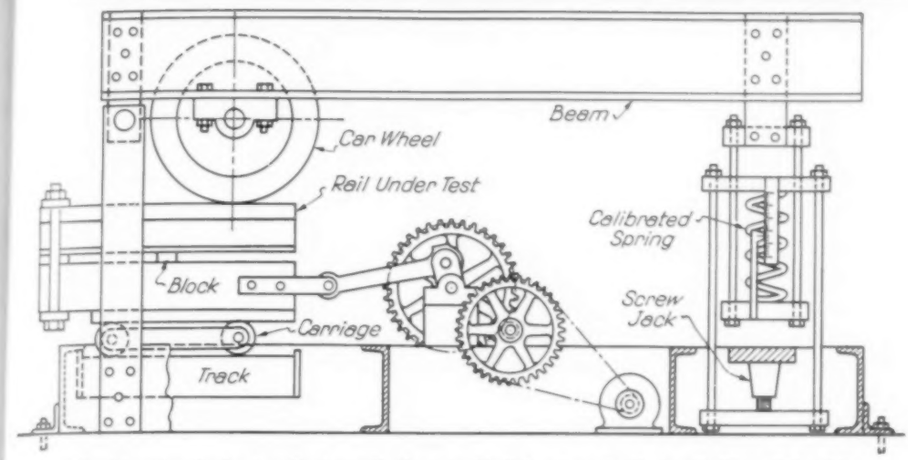
Unfortunately no general agreement has resulted in the minds of rail manufacturer and railway engineer; the metallurgist usually held that transverse fissures were due to excessive wheel loads on improperly maintained track, whereas the railroad man was inclined to blame some unknown variation in steel making and rolling practice which otherwise was producing rails entirely free from this dangerous defect. All recognized the great danger to passing trains, however, yet the only thing which could apparently be done was to remove all rails of a given heat of steel from track as soon as a few of them failed from transverse fissures. Improved methods of inspection, notably the development of the detector car for locating fissures before they have spread to final fracture of rail, have distinctly reduced, though by no means entirely removed, the probability of rail breakage, but the problem of *preventing* such fissures is still important.

A critical review of the published literature and available unpublished tests will not be attempted. It is the present plan to give a brief resume of new studies dating back to Jan. 1, 1931, under the joint auspices and direction of the Rail Manufacturers' Technical Committee and the Association of American Railroads. In this work a staff of about 20 persons, supervised by H. F. Moore, has made laboratory tests of rails and rail steel together with very numerous measurements of track stresses under passing trains. Fuller details of the work are recently published in Bulletin No. 376 of the American Railway Engineering Association.

Since it is clear that an internal transverse fissure is essentially a progressive fracture (or a "fatigue failure" as it is commonly called) spreading out into sound metal from a deep-seated nucleus, it was desirable to build some laboratory equipment for stressing a full-sized rail under a rolling wheel and attempt to develop similar failures under controlled conditions. This machine had been designed during a pre-

'Edited' by H. F. Moore

Research Professor of Engineering Materials, University of Illinois, Urbana



Machine for Inducing Fatigue Failure in Full Section Rails by Rolling Wheel Loads

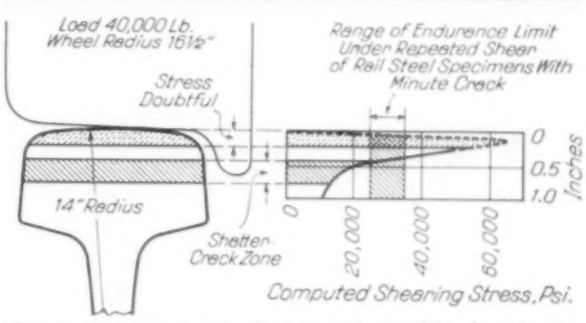
vious investigation, and several of them were built and have been in constant operation. It is shown in diagram at top of this page. A short specimen of rail is pulled backwards and forwards under a wheel which can be loaded up to 80,000 lb. This load is applied through the beam by means of the screw jack, and is measured by the compression of the helical spring. The bending moment can be varied by moving the block.

With this machine it is possible to develop fatigue fractures in full-sized rails. However, the rail itself is a massive piece, and the internal stress distribution is not simply computed. Fortunately Prof. A. N. Talbot had shown in 1920 how to compute the flexural stresses, but it was recognized that the damage could also be caused by a second quite distinct and complex system of stresses, namely those due to elastic (or plastic) movements at and below the small area of contact between wheel and running surface. The latter analysis was made by V. A. Hoersch at Urbana (and almost contemporaneously by N. M. Belajef in Leningrad — the results agreeing).

An *internal* fissure in a rail suggests that shearing stress may be the cause, since the shearing stresses tend to become a maximum toward the center of cross section of a beam. The theoretical shearing stresses below the tread of a rail under a wheel load are shown in the diagram at the right. Actually these stresses are modified by the fact that near the tread of the rail there is plastic action, so that the actual stresses are lessened near the tread of the rail. However, evidence has been found that at a depth of 0.5 in. below the tread of the rail there is fair agreement between theoretical stresses and actual stresses.

These computations indicated that normal wheel loads would stress the metal in the upper part of the head as high as 50,000 psi. in shear. While high, this is probably 5000 to 10,000 psi. lower than the endurance limit. The experience of many laboratories studying the phenomena of fatigue of metals confirms the opinion that localized stress at discontinuities, such as notches, deep scratches, and cracks, is the commonest source of failure in parts subjected to repeated stress. If in any newly rolled rail there existed a crack inside the head, or a highly strained area which under service conditions became a crack, this crack should be especially likely to serve as nucleus for a spreading fatigue failure.

In 1919 Waring and Hofammann showed that some rails, sectioned longitudinally and deep etched, would show evidence of "shatter cracks," as they are commonly called. Photographs of two such are shown on page 48, one without and one with shatter cracks. A great deal of discussion has ensued on their significance (or lack of significance). The question has been raised whether they exist as actual cracks in the rail, or whether they are the result of the etching process or of strain set up by the cutting away of metal. This question is of academic interest only, be-



Shearing Stresses in Head of 110-Lb. Rail Under 40,000-Lb. Load on 33-In. Wheel. Theoretical values near top are modified by plastic movement (cold work) so Belajef-Hoersch formulas are inaccurate in top ¼ in. of rail

cause a condition such that a crack can be started by slight etching or by slight change in internal stress is about as damaging a condition as is the presence of an actual crack.

It would appear that there are veritable cracks in some rails, for careful metallographic studies of unetched rail sections have located cracks with a width (or opening) of the order of 0.00001 in. Furthermore, studies of internal strains in the head of rails cooled on the hot bed (usual American practice) show that these strains are rather small, and in compression rather than in tension. Finally rails known to be shatter cracked were annealed to relieve internal strains, then were sliced and etched and shatter cracks appeared.

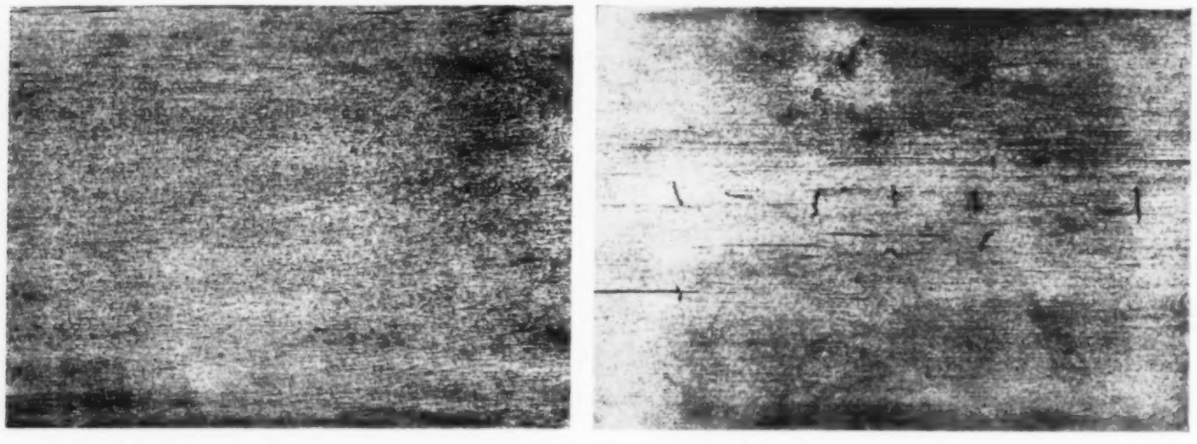
It is believed that the above tests furnish evidence that there are actual shatter *cracks* in some rails as rolled, although the majority of rails rolled in American mills are free from them.

Laboratory studies have been made on about 300 rails (110 and 130-lb. section) furnished by five mills, samples from well-recorded heats. The remaining rails of each heat are now in track under careful observation. Unless otherwise stated the results hereinafter refer to the results of laboratory tests on these rails. There were also furnished 36 pairs of "companion rails" (one of each pair freely cooled on the hot bed and its partner heat treated or cooled in a controlled manner) and 161 rails which have been in service. Whether or not the rail contains shatter cracks is determined by etch test before any further testing is done.

Tests of rails under rolling loads in the equipment above illustrated have yielded fairly convincing evidence that fissures in rails usually originate at shatter cracks which form in the rails during the process of manufacture. All laboratory-developed fissures were in shatter-cracked rails, and about 75% of the service-fissured rails sent to the investigation showed evidence of shatter cracks outside the main fissures. (Of course, this does not mean that *all* shatter-cracked rails develop fissures — a shatter-cracked rail has considerable strength, and doubtless many such rails have worn out in service before they had received enough severe stresses to develop a fissure.)

No failures starting from internal fissures have as yet been developed in the laboratory in newly rolled rails which etch tests have shown to be free from shatter cracks. Such uncracked rails, when they failed under repeated rolling load, failed by a fatigue crack starting from the surface of the rail. Moreover, they required higher wheel loads to cause fracture than did shatter-cracked rails. The photograph on page 49 shows the essential difference between the two types of fatigue failures developed in the testing machines. To date more than 200 rails have been tested in this way.

In laboratory tests internal fissures have been developed in shatter-cracked new rails under repetitions of a wheel load as low as 40,000 lb., which develops a theoretical shearing stress at the zone where internal fissures usually occur just about as high as the repeated shearing stress



Two Rail Heads, Sliced Longitudinally, and Deep Etched; One Without and One With Shatter Cracks

Toughness of Sound and Shatter-Cracked Rail

	Sound Rail		Shatter-Cracked Rail	
	Outside	Inside	Outside	Inside
Tensile strength	100%	102%	100%	63%
Elongation in 2in.	100	102	141	14
Reduction of area	100	85	104	8
Endurance limit	100	—	100	59
Unnotched impact	100	80	123	50

necessary to develop a fatigue failure in rail steel in which there is a small crack. Fatigue tests have been made on specimens of rail steel with and without cracks, using prepared specimens and rotating beam type of testing machine, and the effective stress concentration at the edge of a small crack has been found to reduce the fatigue strength (endurance limit) of rail steel about 50%.

A diagram (page 50) shows the agreement of theoretical analysis with test results on full-sized rails. The endurance limit of uncracked rail steel subjected to cycles of shear varying from zero to a maximum (but not reversed) was found from fatigue tests of rotating beam specimens to range from about 55,000 to 65,000 psi., shown by the upper cross-hatched band. This means that the range of endurance limit under repeated shearing stress for steel with a small crack ranges from 27,000 to 32,000 psi., (using the above mentioned ratio of endurance of sound and slightly cracked metal). This range is shown in the lower hatched band. From the results plotted here it will be noted that all but one of the 24 specimens in which internal fissures were developed were subjected to theoretical shearing stresses within or above this range. All but six of the 30 specimens which had shatter cracks and which failed from other causes than from *internal* fissures, failed under theoretical shearing stresses below this range of endurance of steel with small cracks.

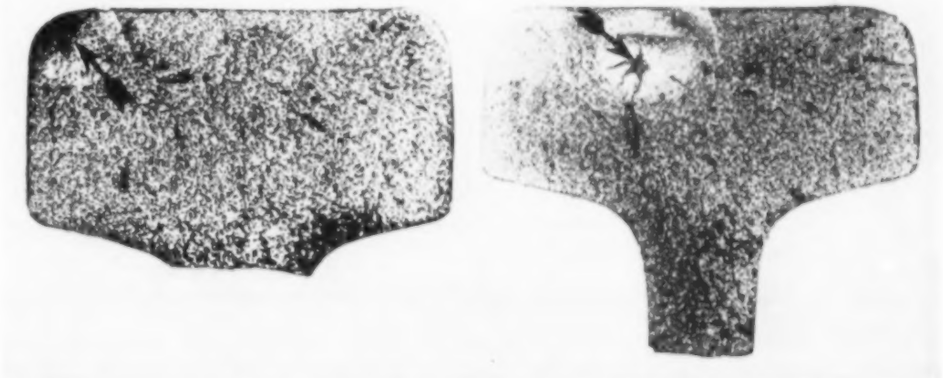
It will be noted that 118 specimens in which etch tests had shown no shatter cracks failed by fatigue failure starting from the surface, and that all but 11 of these 118 specimens failed at stresses below the range of endurance limit for repeated shear for uncracked rail steel. Note also that nearly all of them failed at high flexural stresses.

In view of the wide variation of shearing stress due to various depths of shatter cracks found in rails, the picture of an internal fissure starting from intensified shearing stresses at a shatter crack seems consistent and convincing.

Will Heavier Rails Be Safer?

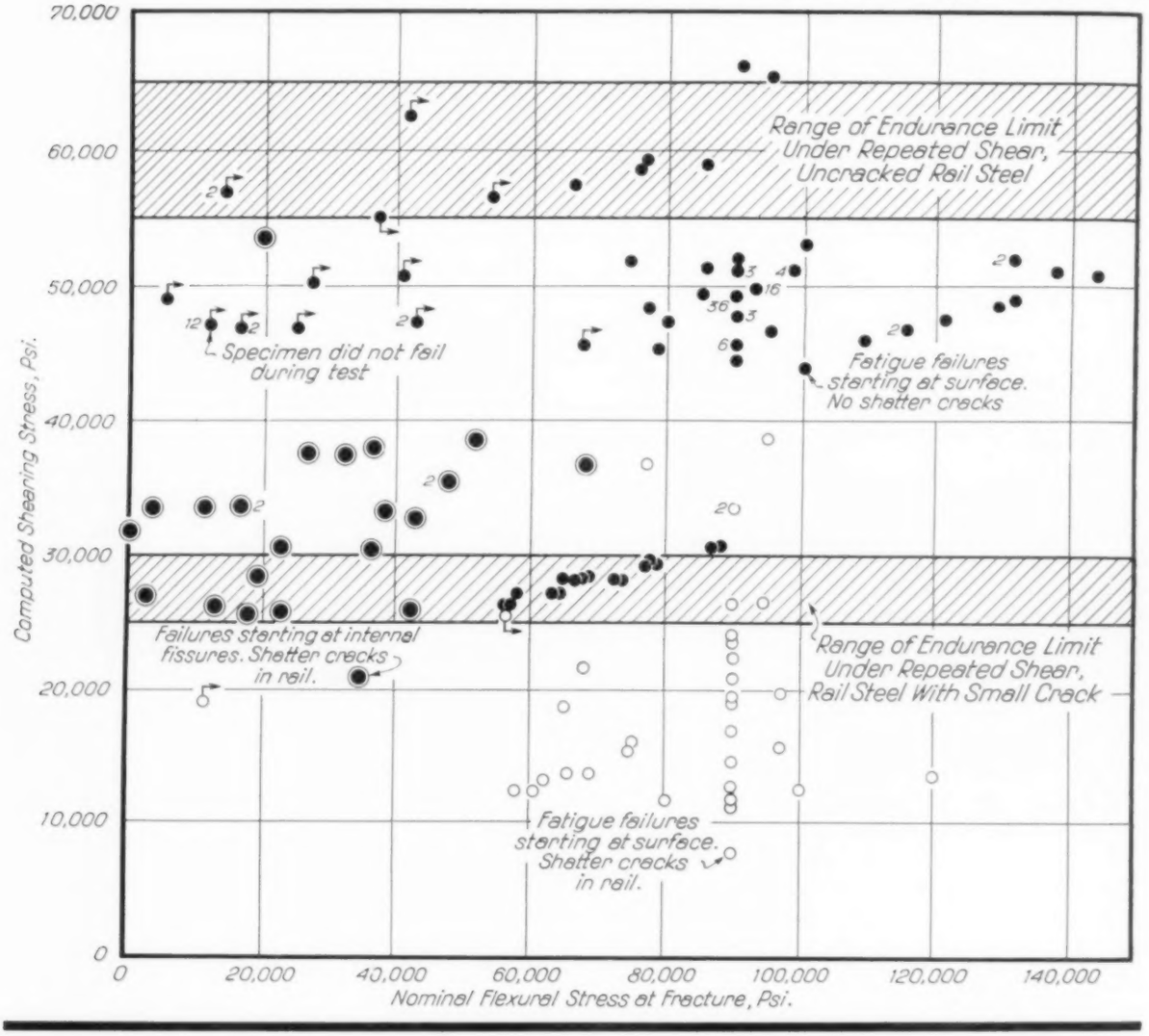
The question of whether heavier rails should reduce failures from internal fissures is an interesting one. The results of rolling load tests, as has been pointed out, show that the start of a destructive fissure seems to be due to the direct action of wheel loads rather than to bending stress. Mathematical analysis indicates that the stresses directly under the wheel load are practically independent of the size of rail. Hence, it seems that the *starting* of fissures would not be hindered by the use of heavier rails. Facts which cannot be presented in small space indicate that bending stresses might be lower in these heavier rails and this would tend to reduce the number of transverse fissures as compared with horizontal fissures.

Along with the above described work, a large number of other physical tests have been made on specimens cut from rail heads. Shatter cracks, if present, are found in the center of the head of



At Right Is Typical Internal Fissure Developing From Sub-Surface Nucleus in Some Specimens Known to Have Shatter Cracks; at Left Is Typical Fatigue Fracture in Sound Rail Starting at Surface (Upper Left Corner) Developed at Higher Wheel Loads

Rolling-Load Tests on Rails. Figures at plotted points indicate number of tests. Shearing stress computed at nucleus of fissure, if developed, or at middle of shattered zone. For sound rails, (black circles) maximum shearing stress is computed from Belajef-Hoersch formulas



a rail and not near the surface. Hence the difference between the physical properties of specimens from near the surface and the properties of specimens from the center of the head should throw light on the effect of shatter cracks on the strength and ductility of the metal. There seems to be no difference in Brinell hardness or Johnson elastic limit of sound and shatter-cracked steel, but the other properties more closely allied with toughness are clearly affected. Average results are shown in the table at the top of page 49, and are of average values in first column; they confirm the conclusion that a shatter crack lowers the resistance of a rail head to the spread of a crack under recurring loads.

An important phase of the investigation has been to determine the actual wheel loads under average traffic. The nominal wheel load on any wheel in a car or locomotive is the dead weight it carries; this is known with a fair degree of accuracy. The actual wheel load at any given point in track may vary widely from this nominal wheel load due to inertia forces set up by unbalanced and flat wheels, by closing solid of springs, and by irregularities of track surface, ballast, and sub-grade conditions. Any increase in wheel load is of most importance, and this will be spoken of as the "dynamic augment."

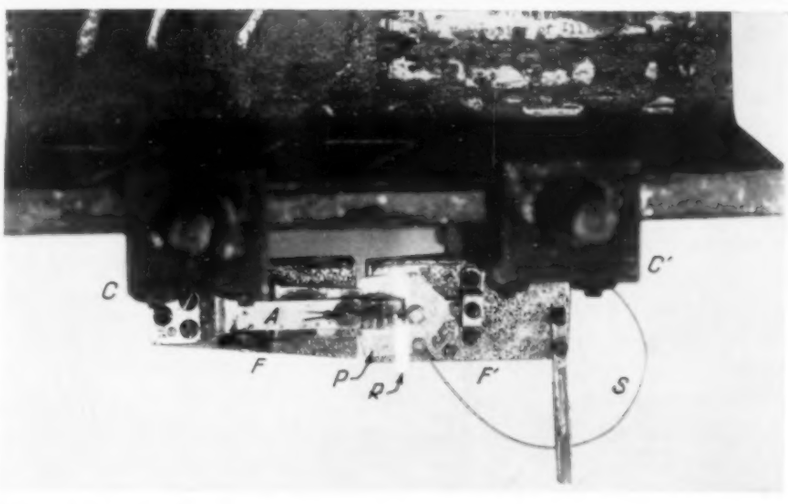
Measurement of actual wheel loads was done indirectly: The elastic elongation of a 4-in.

gage length on the lower flange was measured by means of a DeForest scratch extensometer, which is shown, mounted below a rail in the photograph below, and nearby is a sample record taken by this instrument. The reduction of measurements of elastic elongation of flange to wheel load involves somewhat tedious mathematical computations, taking a far longer time than the obtaining of data.

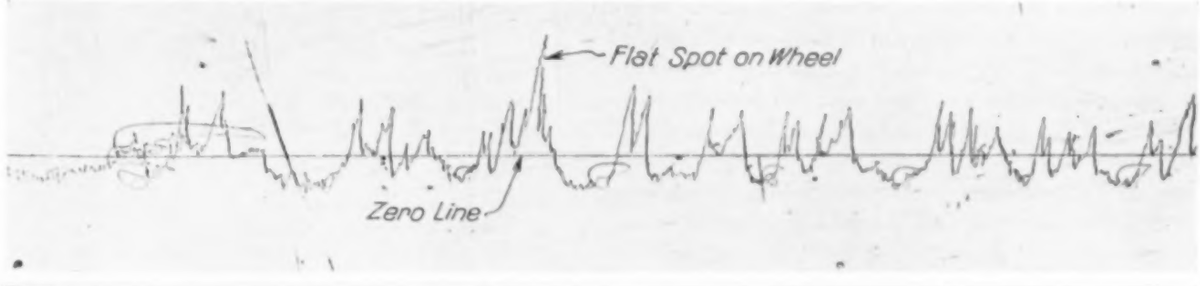
Such field observations and computations to date of writing comprise records of about 54,000 wheel loads on the Baltimore and Ohio Railroad near Dayton, Ohio, and 36,900 wheel loads on the Pennsylvania Railroad near Coatesville, Pa. Most of the observations have to do with freight car wheel loads, and it may be noted that at these two locations actual loads from imperfect car wheels were found to be as high as any loads observed under locomotive wheels. The general results of these tests to date are shown in the curve sheet on page 52.

Both locations represent track in fairly good condition and with heavy rail. They represent about average conditions of rolling stock. Referring again to the results of rolling-load tests in the laboratory, it would not seem unreasonable to assume that any wheel load above 40,000 lb. should be regarded as one which, repeated often enough, might spread a shatter crack into a transverse fissure. The tests in track show that 0.1% of the total wheel loads (one in every thousand) in both locations are equal to or greater than this figure. This clearly shows that the condition of the average rolling stock is such as to induce fatigue failures in unsound rails. Even with ideal maintenance of track and with ideal inspection of rolling stock there would still be some "dynamic augment" of wheel load due to the deflection of track under load. At present it is not possible to distinguish sharply between dynamic augment caused by imperfect track maintenance and that caused by imperfect rolling stock. It can be stated with confidence that both are important.

Even though it is true that neither in the laboratory nor in service do internal fissures develop in *all* shatter-cracked rails, it is also true that in 118 specimens of sound rails broken by fatigue in the laboratory, not one has developed an internal fissure. It is therefore believed that this work has now gone far enough to indicate the undoubted desirability of avoiding any rail containing



DeForest Scratch Extensometer Clamped to Bottom Flange of Rail. Two clamps C and C' carry two flat pieces F and F', one of which carries arm A, to the end of which are cemented particles of diamond dust, and the other carries plate P which can be rotated in the plane of sliding and which in turn carries a record strip R of chromium plated brass. As the base of the rail stretches slightly, due to loads from a passing train, the diamond particles make scratches on the record strip, as magnified 200 X below; a spring S "hitches" the plate slightly downward as the arm A vibrates. Stresses may be figured from this mark.



the so-called shatter cracks deep within the head.

This involves the metallurgical problem of manufacture of sound steel, and the inspection problem of discovering internally unsound pieces. Shatter cracks in rails are not uniformly distributed among all rails of a heat; they are found in some rails and not in others; they are found in some locations along the length of a given rail and not at other locations. Obviously the present method (or any other method) of testing selected portions of random rails will be an unsatisfactory inspection procedure as long as the metallurgical problems are not certainly solved. A non-destructive test which would locate shatter cracks and which could be applied to every rail of a heat would be of great advantage, but at the present time no such test is available. The Sperry method will locate fissures, but not shatter cracks.

A very earnest attempt has been made to find some reliable non-destructive test for shatter cracks in rails. Resistance tests, tests of distortion of magnetic field above a crack, tests of thermal conductivity, tests of modification of sound waves by minute cracks, tests of distortion of magnetic lines of force above a crack (iron dust test) — all these have been tried, and no reliable test has resulted. The difficulty in all cases seems to lie in the extremely minute proportion of volume of steel that is directly affected. So far no device has been tried out by the test party which is capable of detecting a cracked area of less than about 0.5 sq.in.

Tests have shown some promise of success in using a microphone with amplifier and telephone attached to a cooling rail as an indicator of the occurrence of cracks. At present an attempt is under way to devise a recording apparatus to replace the telephone receiver.

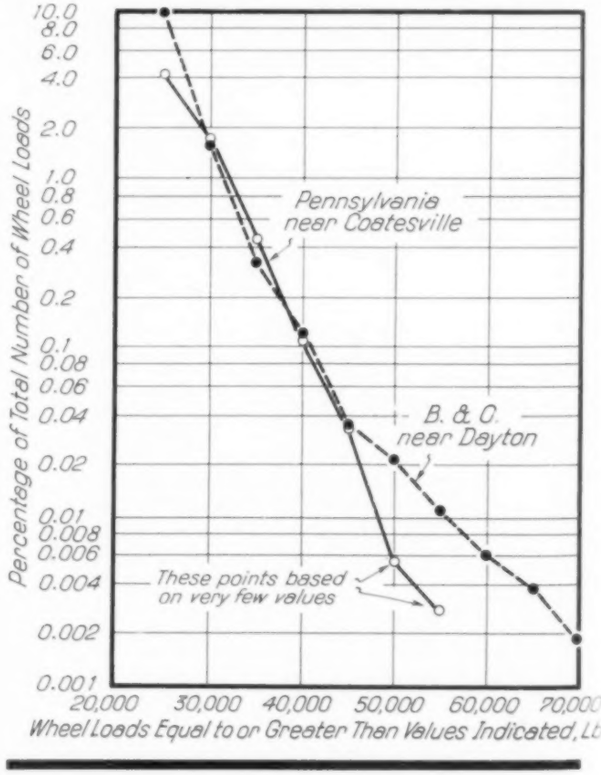
Manufacture of Sound Rails

Metallurgical processes proposed and tried commercially for the elimination of shatter cracks have been applied to the rails after they have passed the finishing pass in the rolls. It is almost certain that internal cracks occur during subsequent cooling, and two types of thermal treatment have been carried out: *(a)* A controlled cooling of the rail, and *(b)* a special normalizing process. Slow cooling means a general reduction of temperature gradient and internal strain throughout the rail, and a gradual adjustment of the metal to equilibrium. A normalizing process gives the steel an improved microstructure capable of resisting more severe cooling strains.

In this connection tests have been made on 72 "companion rails" from four mills. While this is probably too few to draw definite conclusions from, it may be said that some of those cooled on the hot bed had shatter cracks and developed internal fissures in the rolling test, but none of the slowly cooled rails had shatter cracks or developed internal fissures. Some of the normalized rails showed a few shatter cracks but gave good physical tests and developed no fissures. It is evident that the tests so far indicate distinct improvement due to the thermal treatments which have been used.

Especial attention is again called to the fact that the information herein is in the nature of a progress report, and of necessity is only a brief outline of the voluminous and detailed studies conducted; and furthermore that final, definite conclusions are not to be drawn at this time. Additional and incidental lines of work have been, and will be tried out from time to time, both in the laboratory, at the mills, and in the field, as circumstances and developments may warrant.

Frequency of Loads of Various Magnitudes From Freight Car Wheels on Two Railroads. Based on records of 90,459 loads at eight locations



Method for Identification of Inclusions in Iron and Steel

Originated by Wm. Campbell and G. F. Comstock (Proc. A.S.T.M., Vol. 23, p. 521) and Modified by C. R. Wohrman, "Inclusions in Iron", p. 150

Polish Specimen Carefully so as to Preserve Inclusions and Project Magnified Image on Ground Glass by Arc or Equally White Light Without Color Screen

Gray or Black Inclusions

Etch 10 sec. with 10% nitric acid in alcohol

Strongly Attacked
LIME COMPOUND from mold wash (rare)

Unattacked
Etch 5 min. with 10% chromic acid in water (Be careful to observe that the polished surface is wetted by the solution)

Weakly Attacked (slightly pitted or darkened)
COMPOUND OXIDE: (a) either FeO with FeS in solution (usually accompanied by FeO-FeS EUTECTIC), or (b) FeO+MnO and other OXIDES in solution

Note 1: Octahedral crystals are probably MAGNETITE.

Note 2: Both (a) and (b) will be darkened further by 20 sec. sulphur printing (2% H_2SO_4 in water) and destroyed by etching with stannous chloride as indicated below

Attacked
FeS-MnS, rich in MnS. Note: Reaction not always decisive. Any unattacked FeS-MnS will be blackened by next treatment

Unattacked
Note color: (1) Very faint pale grey, (2) Medium or dark grey, and etch 5 min. with boiling alkaline sodium picrate

Completely Blackened
(1*) FeS-MnS, MnS below 50%
(2*) FeS-MnS, MnS above 50% or OXIDE very rich in MnO
* Refer to color before etch

Partly Attacked
(a) OXIDE rich in MnO (will be destroyed by stannous chloride)
(b) SILICATE with some MnO (will be destroyed by hydrofluoric acid)

Unattacked
(or partly attacked in previous treatments) etch 10 min. with a saturated solution of stannous chloride in alcohol

Attacked
IRON OXIDE or (if previously pitted) COMPOUND OXIDE

Unattacked
(or previously pitted) etch 10 min. with 20% aqueous solution of hydrofluoric acid.

Attacked
SILICATE (if previously pitted presence of Mn is indicated)

Unattacked
Repolish and note color and form

If fine particles, very dark color, difficult to polish without pitting and not elongated by hot work is ALUMINA

If color not especially dark, easily polished smooth without pitting

Fairly large angular fragments, showing changeable bright spots as focus is changed, are SAND GRAINS (in steel castings)

Small angular particles, bluish in color probably TITANIUM OXIDE (in titanium treated steels)

Cream Colored (Pale Yellowish) Yellow, Red, or Purple Inclusions

Etch 10 min. with boiling alkaline sodium picrate

Attacked
IRON SULPHIDE (pale yellowish)

Unattacked

Purplish color, rather easily polished smooth, is CHROMIUM OXIDE

Yellow cubes or cubic form is ZIRCONIUM NITRATE

Pinkish color, strongly angular form, rather difficult to polish without pitting is TITANIUM CYANO-NITRIDE

Supplementary Tests

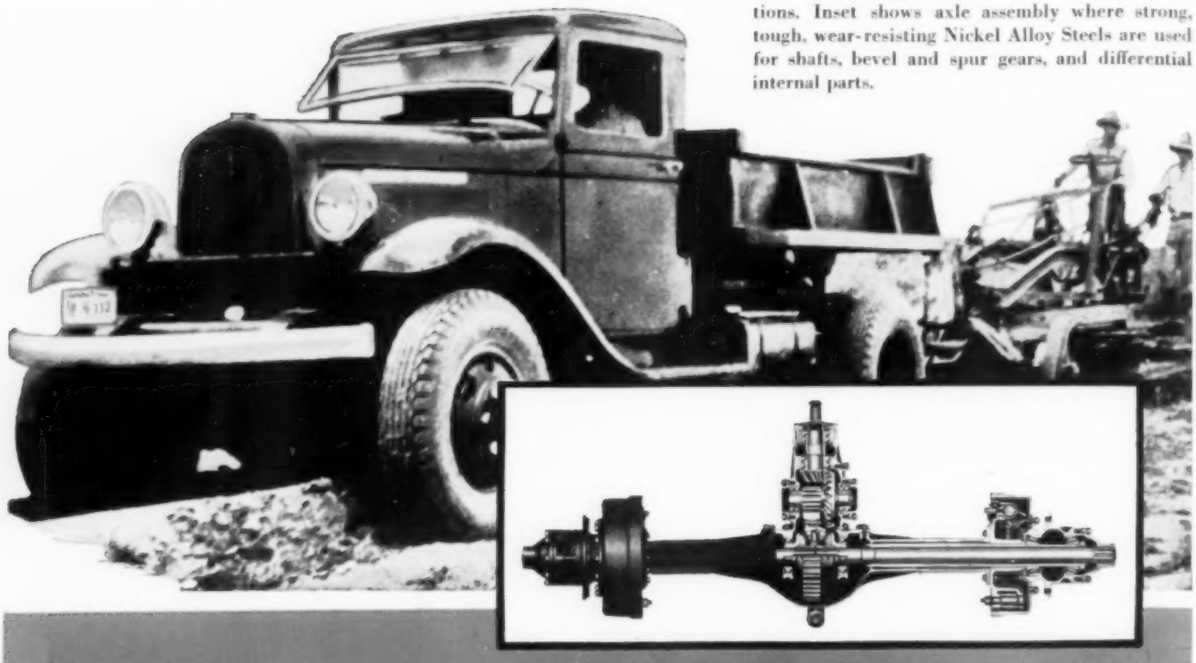
In all instances check determinations in the light of the evidence of a careful chemical analysis, and, whenever possible, by other methods, such as:

I Sulphur Printing
(for 20 sec. using a 2% aqueous solution of H_2SO_4)
(1) Dissolves all FeS-MnS inclusions
(2) Partly dissolves (pits) FeO containing FeS and OXIDES of other metals in solution
(3) Leaves unchanged: IRON SULPHIDE (pale yellow), pure IRON OXIDE (medium grey), SILICATES (dark grey)

II Matweieff's Tests
(a) Dilute tartaric acid does not attack OXIDES or SILICATES, but colors MnS lightly and FeS decidedly
(b) heat sample in hydrogen at 1600°F., OXIDES are reduced, SILICATES and SULPHIDES are uneffected
(c) Repolish (b), etch with dilute $FeCl_3$ in alcohol, if reduced oxide particles are colored deeply they contain some Mn

III Rohl's Test for Sulphides
Short etch with 1% picric acid in alcohol, then temper to dark yellow. FeS turns dark blue to reddish violet, and MnS turns dull grey to bright white.

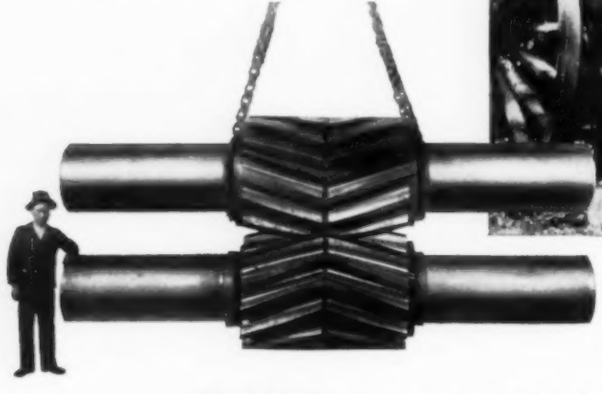
Truck turns tractor. Marmon-Herrington heavy duty unit hauling scraper in road building operations. Inset shows axle assembly where strong, tough, wear-resisting Nickel Alloy Steels are used for shafts, bevel and spur gears, and differential internal parts.



NICKEL

Reduces Breakage and Wear in Metal-to-Metal Contacts

None of your "blooming" business requires sturdier materials than pinions. This pair, weighing 80,000 pounds, are made of Nickel Chromium Steel to give greater resistance to stress and wear. Installed in blooming mill of Pittsburgh Crucible Steel Company.



Tough as a tank, this timber towboat. An Allis Chalmers Monarch "75" logging in Oregon. Inset shows transmission assembly. All gears of Nickel Alloy Steels—selected for this punishing service because of superior toughness and high resistance to stresses and wear.

FREE! Send for our handy celluloid vest pocket size "Hardness Conversion Table." Quickly gives approximate relation between Brinell, Rockwell and Shore hardness values and corresponding strengths of Nickel Alloy Steels. Address Dept. J-3

THE INTERNATIONAL NICKEL COMPANY, INC., 67 WALL ST., NEW YORK, N. Y.

Metal (and in fact many substances) may be effectively heated by circulation of hot air. This air may be products of gas or oil combustion. Principal advantages of the system arise from the uniformity of heat in all parts of the load

Heat Treatment by Forced Convection

IT WILL BE RECALLED, from elementary physics, that heat may be transferred from a hot region to a cool one in three ways — conduction, convection and radiation. Without attempting a rigorous scientific definition of these terms we may illustrate by quoting a common example of each: The handle of a skillet gets hot from conduction; a hot-air furnace heats a house by convection; the sun heats the earth by radiation.

Convection, of course, comes into play whenever the atmosphere in a furnace or oven moves, or whenever a liquid bath is stirred. However, in this discussion the term "forced convection" will apply only to circulating gases, moved mechanically and utilized as a means of conveying heat from one location to another. In many cases forced convection is most readily carried out by using a mixture of products of combustion with returned recirculated gases. It is entirely possible, however, to accomplish the same thermal results by circulating inert or reducing gases heated in a stove or recuperator; in this case, all of the thermal advantages obtainable by circulating products of combustion may be derived with the additional advantages of preventing or controlling surface changes such as oxidation, discoloration or carburization. A notable example of this principle applied to the drawing of hardened transmission gears was described at length by E. M. Kingsley in the leading article in METAL PROGRESS, January 1933 issue.

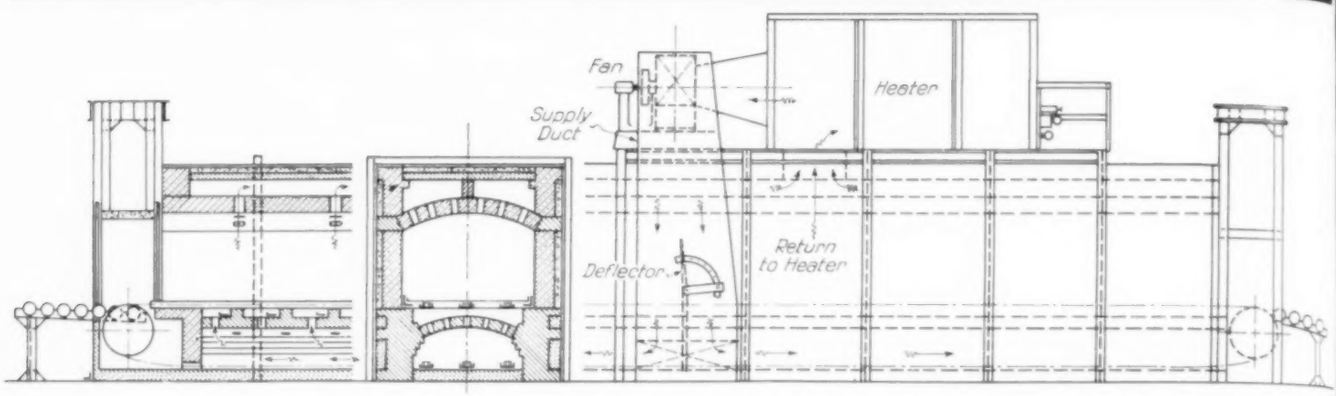
There is no theoretical limit to the temperatures at which forced convection may be applied with advantage, but from a practical standpoint it has been found that the mechanical equipment for moving gases is still somewhat unsatisfactory above temperatures of 1600° F. to 1800° F. As a result, forced convection has been largely (but not exclusively) employed in the temperature range between 200 or 300° F. as a low limit and 1500 to 1600° F. at the top. This range covers the entire field of drying and baking, practically all drawing operations on steel, as well as the relieving of strains in forgings or weldings, and the full annealing of many non-ferrous metals. Typical applications and the results obtained will be mentioned later in this discussion.

Heat treatment at low temperatures by forced convection is a young idea as compared with such time-honored equipment as liquid baths. These also transfer heat largely by convection, and a clear distinction should be made between the two systems.

Liquid baths usually consist either of oil or low melting salts. When used for treating metal, more or less of the material of the bath adheres to the surface of the article being heated, and is a source of annoyance and expense. The articles must be cleaned after drawing and there is a continued loss of the materials forming the bath due to carryout.

Furthermore, any liquid bath is slow to acquire a uniform temperature throughout its mass,

By W. A. Darrah
President, Continental Industrial Engineers, Inc. . . . . Chicago



Diagrammatic Representation of Forced Convection as Applied to Through Type of Conveyor Furnace. Hot gases from heater are blown into passage below hearth, thence up around work through many openings below conveyor, and are sucked back to heater through vents in roof and upper flue.

particularly in the relatively low temperature ranges. Heat withdrawn from the central portion of a liquid bath cannot be promptly replaced by transfer from heated pot-setting, through the pot wall and relatively large mass of liquid. Therefore, it is difficult to obtain a high degree of uniformity with either an oil bath or salt bath used in low temperature heating operations.

The second alternative, formerly used in place of forced convection, is radiant heat. Such heat may be supplied from relatively cool radiators (as steam coils in the case of baking and drying operations, or surfaces surrounding circulating hot oil or similar liquids) or, more efficiently, from glowing radiators such as electric resistance elements or from the hot surfaces of fire-box walls.

There are several fundamental difficulties inherent in the use of direct radiation as a means of obtaining uniform heating. In the first place, radiation is almost entirely intercepted by any solid body. Therefore, any chamber filled with articles being heated and supplied with a source of radiant heat is subject to "shadows" — that is to say, articles adjacent the source of radiation will become rapidly heated to a high temperature whereas articles or portions of articles in the central part of the chamber, shielded by other articles, will be very slowly heated. As a result radiation cannot be depended on as a source of *uniform* heat application in operations such as drawing, annealing or baking.

The improvements, therefore, to be effected by using forced convection as a means of heat application may be summarized in the following enumeration:

1. Maximum rate of heating consistent with uniformity.
2. Elimination of large temperature differences within different portions of the article being heated.
3. A resulting unusual uniformity in properties of all parts of all articles.
4. High fuel economy.
5. Relatively low initial cost.

The manner in which these objects are obtained will be pointed out later in the discussion.

Operating Principles

Since heating by means of forced convection may be considered as a problem of transferring heat from the point of generation to the point of utilization, the essential parts of the system include a source of heat generation (which, in the case of fuel-operated equipment, would be a combustion chamber); second, a chamber preferably removed from the combustion chamber where the articles are placed to be heated; and third, a fan with a duct system to draw the hot products of combustion from the combustion chamber, pass them through the heating chamber, and return them to the combustion chamber for recirculation.

The diagram above shows these typical elements arranged so that the circulating fan is at the highest point of the system (the words "highest point" being used in a thermal sense). This arrangement is probably the simplest and one of the most practical. An alternate method is shown on the opposite page in a furnace cross section in which the fan is located in the return

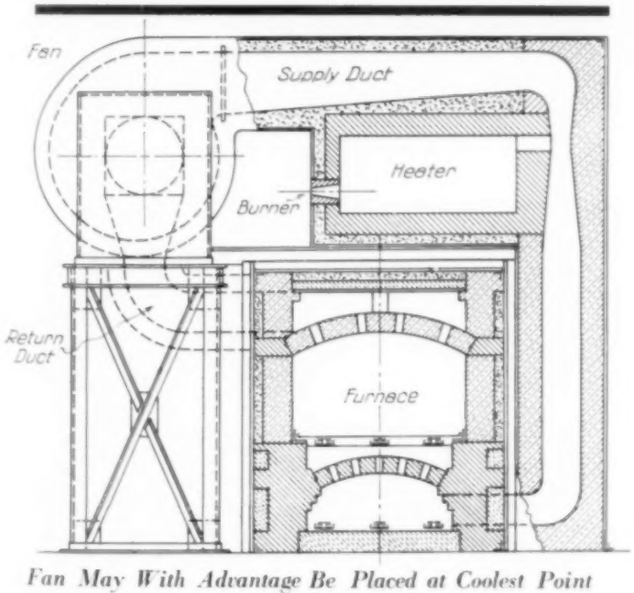
circuit of the hot products of combustion and discharges through a venturi nozzle, the reduced pressure at that constriction serving to induce the hot products of combustion into the circulating gases. This second and newer arrangement is somewhat more suitable for high temperature operations and materially raises the permissible operating limits with a given design of fan.

The fundamental calculations of a recirculating system are relatively simple, but the details of application involve a rather broad range of experience.

If the amount of heat to be transferred is represented as c in British thermal units per unit time, we may write the fundamental equation

$$c = Vs(T_1 - T_2)$$

where V indicates the volume in cubic feet of the moving gases passing into the heating chamber in unit time (figured at standard pressure and temperature), T_1 the temperature at which they enter the heating chamber, T_2 the temperature at which they leave the heating chamber in degrees Fahrenheit, and s the heat constant of the circulating gases. The specific heat of common gases increases somewhat with the temperature, and actual figures may be taken from handbooks or Richards' Metallurgical Calculations. For most practical purposes, approximate computations may be made assuming the circulating gases to have a heat constant of 0.04 to 0.05 B.t.u. per cu.ft. (measured at standard temperature and pressure).



Fan May With Advantage Be Placed at Coolest Point in System. Hot air is added to circulation, making up for radiation and heat taken out by work, by sucking in hot gases from combustion chamber at throat of venturi

It will be noted that the difference between the temperature of the gases entering and leaving the heating chamber is the important factor in determining the amount of heat transferred rather than the ultimate temperature used. In order to obtain reasonably close control, this temperature difference should range between 50 and 100° F. In order to determine, then, the required volume of circulating gases it is merely necessary to determine the amount of thermal work to be done — that is to say, the amount of heat required to raise the temperature of the work — and divide by the difference between entering and leaving temperature multiplied by the specific heat of the gases at the mean temperature. Practical considerations will usually dictate the permissible temperature drop, which in turn will determine the volume of circulating gases.

Surface Exposed

Another factor of vital importance in connection with forced convection heating is the amount of surface on the material which is receiving the heat.

Each square foot of surface subjected to the flow of circulating gases will absorb a definite number of heat units, which is dependent on the temperature difference between the circulating gases and the surface, the velocity of the circulating gases and the nature of the surface. This may be expressed by the equation

$$H = CA\varepsilon(T_g - T_s)$$

In this equation, C equals a numerical coefficient which in fact varies with the operating temperature; for normal conditions C may be assumed to average about 3 B.t.u. per sq.ft. T_g and T_s indicate the temperature of the circulating gases and the temperature of the solid being heated, while ε represents a surface constant varying with the color, texture, smoothness and material of the surface. In the case of steel forgings, ε may be taken approximately as 0.9. The surface area is indicated by A.

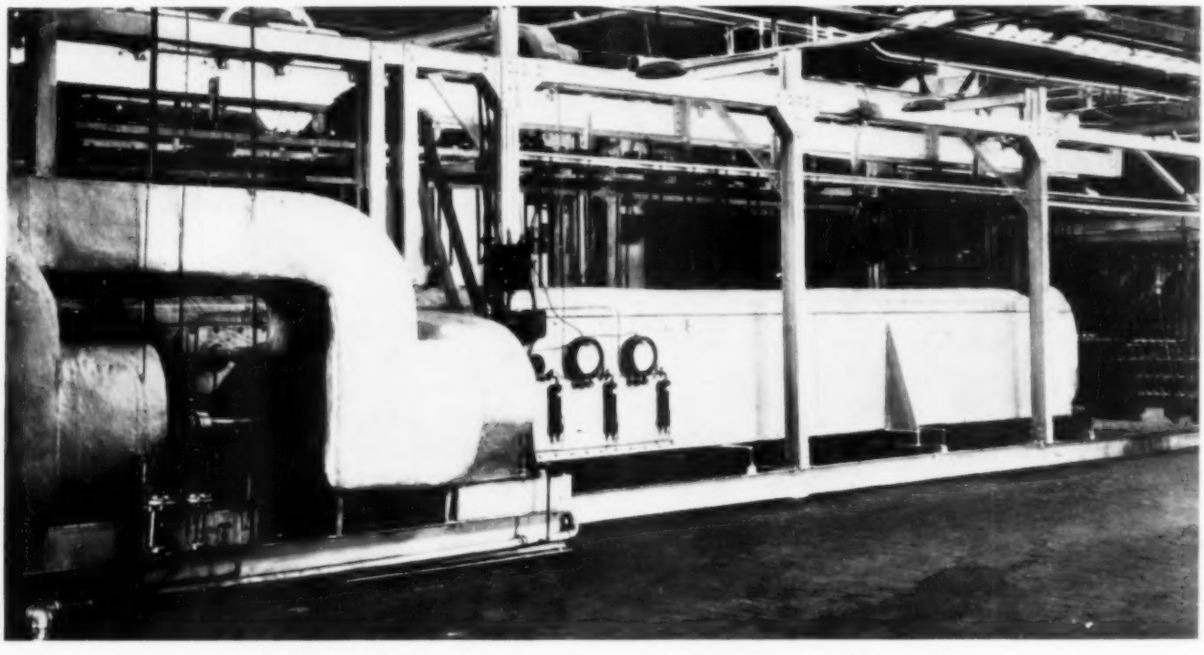
The above equation is of prime interest in that it states the rate at which it is possible to deliver heat to a given surface, having specified the temperature difference and other factors. In other words, this equation determines the maximum permissible rate of heating under a given set of conditions and, therefore, the maximum capacity of a given unit.

The optimum velocity of the circulating gases appears to be around 1000 ft. per min. This is subject to variation, being higher at higher gas temperatures. Higher velocities also serve to apply the heat with greater uniformity, but velocities materially greater than 1500 ft. per min. ordinarily involve excessive power and special fans without conferring any corresponding advantages.

The volume of circulating air must under all conditions be sufficient to give an active circulation throughout the whole cross section of the chamber being heated. Otherwise the heating will be non-uniform.

There are a great many other factors of much importance in the design of a forced convection system. Of even greater importance than the equations given is the proper selection of the numerical coefficients and constants, which are subject to variation for many reasons. The art of designing these systems has been developed by the writer's organization by continuous effort and experience of several years, and many of the unique features are covered by American patents.

Probably a better way to indicate the results of the above principles is to give some figures for commercial furnaces built and operating. The field of application is exceedingly broad, covering in the lower temperature range practically all of the commercial operations of drying and baking such materials as painted surfaces, foundry cores, paper, board and automobile parts. From the metallurgical standpoint forced convection or recirculation is applicable both to steel and the non-ferrous metals. In the latter case it may be used for relief annealing of brass and copper alloys, for the full annealing of copper, brass and related alloys, for producing controlled degrees of hardness in copper and aluminum alloys and for aging and hardening aluminum and aluminum alloys.



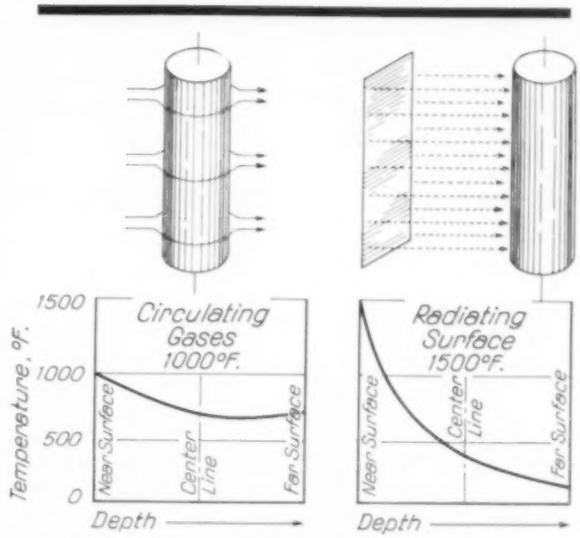
Side View of 60-Ft. Tempering Furnace for Transmission Gears. Two fans keep temperature at 450° F. Capacity of furnace is 1800 lb. per hr.

Commercial Applications

We shall now illustrate two examples in metal working plants, one for low temperature and one for relatively high temperature work.

The above photograph looks toward the discharge end of a 60-ft. furnace for tempering transmission gears (S.A.E. 5140, oil quenched from a cyanide pot) at 450° F. This is taken from Mr.

Kingsley's article mentioned at the outset. The furnace is in fact a long, insulated tunnel with several side entrances for the hot air, and numerous openings through a false bottom to a flue for carrying the gases back to the circulating fans. A narrow slot is open along the roof centerline, to pass hangers from an overhead trolley, each hanger holding a rack with about 60 lb. of gears. Passage of the work from end to end of this heated tunnel requires about 80 min. Capacity is 1800 lb. per hr. of tempered gears.



Diagrams Showing Methods of Heating and Resulting Temperature Gradient When Heating by Convection Currents (Left) and by Radiation (Right). In the latter case, cold metal receives heat at its surface at a rate too high for transmission by conduction inward, and steep temperature gradients exist in the piece

This furnace needs two fans to circulate the gases properly. Gas is burned in a separate "dutch oven," and enough hot air is added to each fan casing (through dampered flues) to make up losses in hot air in the furnace through entrance and discharge doors, roof slot, and losses in heat through radiation and that carried out in the hot gears. Fan No. 1 discharges sidewise into the oven and the air is deflected so it travels against the work toward the loading opening; its circulating air is about 70° F. hotter than in the discharge end, so as to bring the gears up to temperature rather rapidly.

The heat generation chamber is fired with two gas burners, one controlled by a hot bulb placed in the passage from this chamber to fan No. 1, and the other by a hot bulb on the discharge of fan No. 1. A similar pyrometric control for fan No. 2 adjusts the damper opening between fan and combustion chamber.

Costs of this operation are very moderate, figuring less than $1.00 per ton of heat treated gears. The principal items (exclusive of burden) are labor, fuel, power and miscellaneous supplies, as follows:

Labor, 1 man @ 50¢	= 80.50
1000-B.t.u. gas fuel, 330 cu.ft. @ 42¢/M	= 0.14
Power and miscellaneous supplies	= 0.12
Total cost per hr.	= 80.76

Uniform heating is particularly necessary in accurately cut gears to avoid dimensional changes, which means noisy transmissions. (It is also desirable for cold drawing stock; experience seems to indicate that metals correctly drawn with the recirculating process have fewer rejects on forming, due in considerable part to the uniformity of grain size which may be obtained.)

The explanation of these uniform characteristics of a metal treated by the recirculating method undoubtedly lies in the relatively close balance which may be obtained between heat absorption and heat delivery. This can be best illustrated by comparing the two adjoining diagrams. A typical condition is indicated at the left when heating a cylinder of metal by circulating gases and the curve below the diagram indicates the relative heat distribution at a given time between center and outside of the metal. It will be noted that this difference is reasonably small, owing to the fact that the rate of heat delivery is always slightly less than the rate of heat conduction.

Hot Spots From Radiation

When transferring heat at a commercial rate by radiation, on the other hand, it is necessary that the radiating surface be much hotter than the circulating gases in the case of convected heat. This is shown in the right hand diagram, and means that the surface of the metal receives radiant heat at a rate considerably greater than it can travel inward, and as a result a very marked temperature difference is created between surface and center, and a still greater difference between the near surface and the far surface which is shielded.

These diagrams clearly indicate that different parts of the metal will receive widely different heat treatment in the case of radiation, but closely similar heat treatment in the case of con-

vection heating. This condition is especially noteworthy in early stages of heating.

This marked difference in rate of heat distribution whenever radiation is used to transfer heat inevitably results in a differential heat treatment and in most materials causes a different grain size or condition in various parts of the metal. The relative importance of this matter of course varies with the nature of the metal and required accuracy of the finished part.

In the case of brass the difference has been sufficient in one instance to exclude one manufacturer's product and place the business elsewhere. One manufacturer of steel cutting tools was able to eliminate all rejections (previously numerous due to lack of uniformity).

Applications of this system to steel parts include such items as roller and ball-bearings, gears, shafts, knives, shears, cutting members, razors, and special parts requiring close control of grain size, hardness, and strength. It is of course obvious that weight may be reduced in members having uniform physical properties.

Higher Temperature Work

Tunnel furnaces have been built for annealing non-ferrous alloys and operate at a maximum temperature of 1200° F. A furnace of this type will anneal copper or brass with an expenditure of fuel represented by 5 to 6 gal. of oil per ton of product and will give a surface which is clean, free from soot, oil or dirt, and only very slightly tarnished. (In this connection it may be mentioned that this same type of apparatus is used both for drying wall board and table salt, and for baking food stuffs. In no case is there any discoloration of the product or any odor or taste from the fuel.)

One such furnace as mentioned above is about 36 ft. long with a hearth which is 42 in. wide. When handling tightly coiled strip brass the capacity is about 3000 lb. per hr. When handling tube or rod the capacity may be increased almost 100% because of greater surface to absorb the heat. On coiled strip the heating time is about three hours, but on rod or tube it is greatly reduced — in some cases to only 10 or 15 min. Since heat delivery is at a slightly lower rate than heat penetration soaking proceeds with heating.

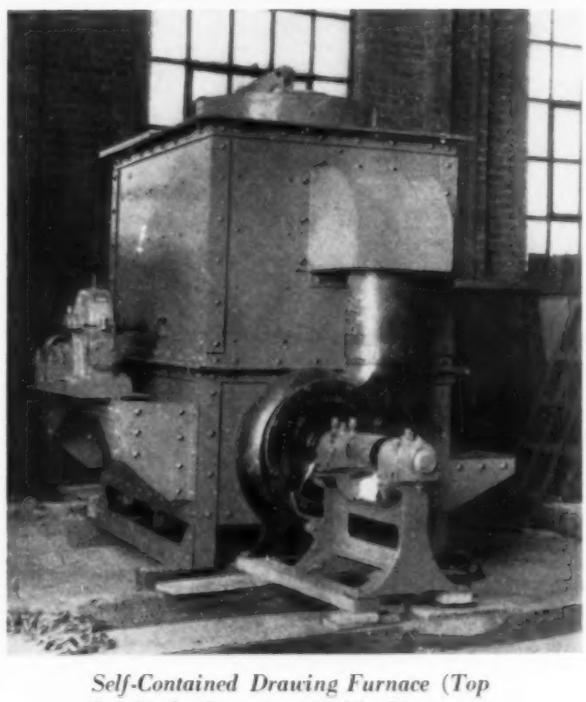
Owing to the relatively small thermal head in a furnace of this type the outer metal is identical in character with the inner metal and the surface is not scaled, thus making the process very desirable for so-called finish anneal.

A mass of light articles such as small brass or copper stamped articles can be handled in this manner to unusual advantage, as the circulating medium penetrates immediately to the center of the mass. In contrast, a radiant heat furnace heats only the surface articles promptly, and the interior of the mass is insulated by the dead air spaces and shaded by the outer pieces. Small articles or stampings may be repeatedly heated and re-pressed or re-drawn without cleaning. This process may be known therefore as a "clean anneal" in comparison to a bright anneal. (By controlling the atmosphere a bright anneal may be obtained.)

Accurate control of grain size may be obtained by controlling time and temperature of the heat cycle. A properly built furnace may also be rapidly heated from room temperature. As a specific example, a furnace between 30 and 40 ft. long, 6 ft. wide and 12 ft. high may be raised from 100 up to 500° F. in less than 2 hr.

Modern construction is represented in furnaces of this type, built as they are throughout of insulating refractories, backed up with block insulation and mineral wool. The rotor of the circulating fan is of a high chromium alloy and the housing of steel or cast iron, well insulated.

It will be noted that the method of heating here discussed may be *(Continued on page 80)*



Self-Contained Drawing Furnace (Top Loading); Capacity 500 Lb. Maximum

A lead bearing alloy (containing a total of 2.5% of calcium, tin and other hardeners) has unusually high strength at temperature near melting and consequently is favored for high speed gas engines

A New Bearing Metal —a Lead Base Alloy

IN THE PRESENT machine age, where greater speeds and horsepower are being used, the working members of our machines are being taxed to new limits. This necessitates the use of superior materials with especially good properties at the temperatures and pressures of operation. The internal combustion engine is a typical case where, in the past ten years, the horsepower has been progressively increased while maintaining approximately the same weight. This has been accomplished principally through the use of hitherto unknown and stronger alloys in various parts of the machines, ranging all the way from valves, cylinders, pistons and connecting rods to bearings.

Conditions as they exist in main and connecting rod bearings in a modern automobile engine were discussed by Stanwood W. Sparrow of Studebaker Corp. before the 1934 meeting of the Society of Automotive Engineers. Babbitt has been the favorite material for years; its composition has not been standardized by all manufacturers but is around 88 to 90% tin with the balance antimony and copper (usually more of antimony than copper). This is a rather expensive alloy, and the industry has turned to "thin-back bearings," that is, those having a thickness of shell not exceeding $\frac{1}{16}$ in., adherently lined with about 0.030 in. of babbitt.

By C. H. Hack
Research Laboratories, National Lead Company, Brooklyn, N. Y.

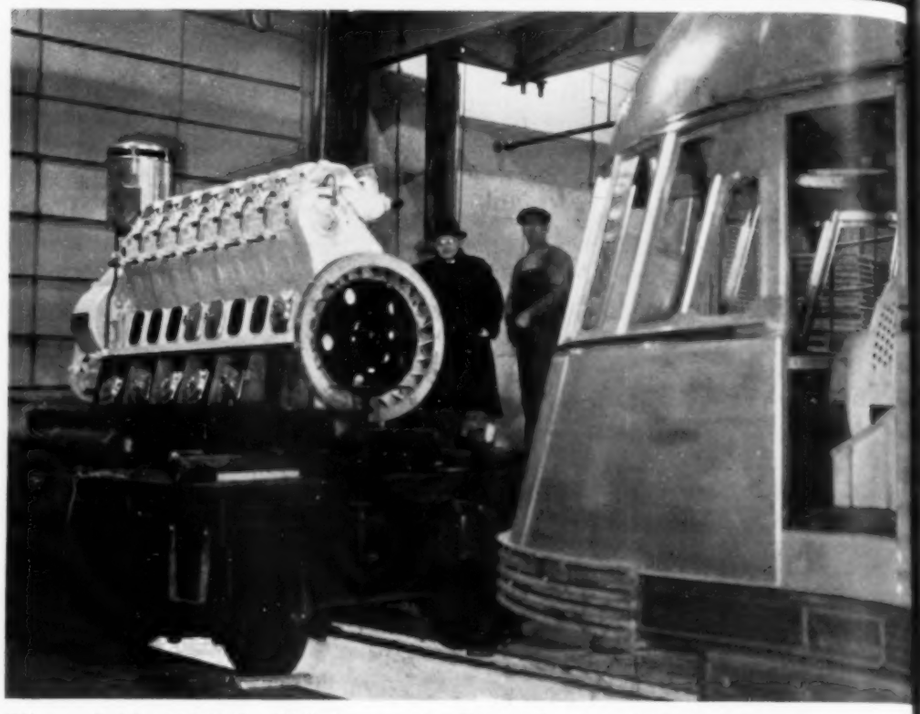
Many failures in such bearings can be attributed to high temperature, ascribed by Mr. Sparrow in the above-mentioned paper to an oil film inadequate to prevent metal-to-metal contact. This in turn is probably due to increased loads resulting from higher gas pressure and the greater inertia and centrifugal force of more rapidly moving parts, acting in conjunction with unavoidable errors in assembly and alignment. As he says, "Experience has made the automotive engineer a pessimist. He designs his lubricating system to maintain a film of oil between the journal and bearing, but realizes that he will not succeed and takes care to select a bearing material that will minimize the harmful effects of his failure. The widespread use of babbitt may be due to the fact that metal-to-metal contact over a small portion of the surface causes the bearing material to soften and crush without damaging the journal or developing enough heat to destroy the remainder of the oil film."

It is when these conditions become too drastic that the formerly used bearing metals become unsatisfactory, and this has led to much research into bearings, not only for automobile engines, but also for railroad rolling stock and heavy and high speed machinery wherever it may be found.

Important qualifications for a good serviceable bearing metal are strength, hardness and resistance to compression, with a structure of relatively hard microscopic particles intimately and uniformly dispersed throughout a softer matrix. Also a bearing must have a certain amount of plasticity in order to conform to the shaft and thus distribute the load uniformly. It

should have good founding qualities, and (if used in large bearings) be capable of remelting without serious change in composition. It should not be damaged by corrosion by commercial lubricants at operating temperatures, or by industrial atmospheres.

Unfortunately most of the above physical requirements can be stated in a qualitative manner only; conditions in service are so complicated that preliminary laboratory tests can, as yet, only give an indication of the serviceability. There are a good many alloys which meet these above general conditions at room temperature but nearly all of them are lacking in some of these qualifications at the higher temperatures and loads which many of our present bearings are called upon to meet. It is in reality these properties at the higher temperatures which determine success or failure of not only many of our bearings but the machine of which they are a part.



Winton-G. M., 666-H.P., High Compression Engine Ready to Be Placed in Boston & Maine's Streamlined Train "The Flying Yankee." Connecting rod and crank axle bearings are severely punished in engines of this type. Courtesy E.G. Budd Co.

Many New Bearings Tried

Manufacturers of bearing metals have been awake to this fact and we are now witnessing the use of many new bearing alloys which have superior properties at the higher temperatures. Two have received much attention from the automotive industry, one a series of copper-lead alloys containing from 25 up to 45% of the latter metal in suspended particles, and the other of cadmium with 1.25 to 1.5% nickel. [The cadmium-silver bearing metal might be included in this second category.—EDITOR.] Both have a much higher melting point than babbitt and their physical characteristics are less affected by temperature — in fact, are operative at the melting point of babbitt.

In the copper-lead alloy, metal-to-metal contact sweats out a film of lead which may have enough inherent lubricating power to prevent seizing when lubrication fails. Prevention of seizure may be partly due to the harder steel journals required for this bearing alloy.

Another type of bearing metal which has received much attention from railroad and diesel engineers contains 97 or 98% of lead, hardened with some combination of several elements. An alloy of this type called "Bahnmetall" has been the standard bearing metal on the German State Railways since the War. It is lead containing about 0.5% each of sodium and calcium, together with about a tenth as much lithium and aluminum. "Satco metal" is a patented alloy manufactured in America by the National Lead Co. and contains approximately 97.5% lead, hardened with several other elements, including calcium and tin.

This alloy has already passed well beyond the experimental stages and is now being used to a greater and greater extent in machines where the service conditions are very severe. One of the major American railroads has used it as standard for the last six years for such purposes as locomotive and tender truck bearings, hub liners and passenger car bearings, and has found it much superior to the ordinary metal for lining bearings on older rolling stock.

Many other American roads are now using the same alloy in steam services. Much more severe service as to speed and unit pressures (although under better lubrication conditions) must be met in the bearings in all main and connecting rods in the diesel engines which power the new streamlined trains, among the most prominent of which are the Union Pacific's "M-10001," the Burlington's twin "Zephyrs," the Boston & Maine's "Flying Yankee," and the New Haven's "Comet." All of these trains have been subjected to grueling tests, particularly the "Zephyrs" and the "M-10001," which have made transcontinental runs at unprecedented speeds. The uniform freedom from serious breakdown which has characterized all these tests indicates that the Satco lined bearings are entirely capable of withstanding the loads which modern high speed transportation imposes on mechanical equipment. It is therefore not surprising to find these same bearings in several 1200-hp. diesels built by the Winton Engine Co. of Cleveland for the United States Navy.

A War Discovery

A historical note concerning the hardened leads will be of interest. During the early part of the War, when tremendous amounts of shrapnel bullets were being made of antimonial lead, there was a shortage of antimony and a substitute was sought. Francis C. Frary (now director of research for Aluminum Co. of America) and S. N. Temple secured patents covering alloys of lead with barium and calcium, and great tonnages were made by United Lead Co. of Keokuk, Iowa. The process used was the slow electrolysis of a molten mixture of chlorides on a pot of molten lead. (More recently Dr. W. Kroll of Germany has patented the quicker method of stirring calcium carbide in a flux to be reduced by the main body of metallic lead.)

Study of the binary equilibrium diagrams indicates that metals of Group I and Group II in the periodic system have considerable solubility in solid lead just below the solidus, but very little at room temperature. Hence an excess constituent is precipitated out of the ground mass, either during cooling or by utilizing the now well-known principles of precipitation hardening. In the case of the calcium-lead alloys an additional hardener appears in the form of the intermetallic compound Pb_3Ca. The solid solubility of calcium is about 0.10% at 600° F. and as little as 0.01% at room temperature, so a very little of it is required to harden the lead matrix — nearly all appears in the hard compound Pb_3Ca.

While the lead-calcium-barium alloys were promoted as superior bearing metals after the War, the time was not right for their commercial acceptance. An interesting use of such alloy at present is a lead with as little as 0.03% of calcium, which (as determined by Bell Telephone Laboratories) makes a better cable sheath when properly aged than the previously used 1% antimonial lead, being superior in hardness, tensile strength, fatigue strength, and resistance to creep. However, age hardening effects cannot help much in a bearing, for the hardening constituents agglomerate at the temperatures at which a bearing must operate.

Satco metal, as mentioned above, is a 1% tin-lead alloy, hardened with considerable calcium. The structure as revealed by polishing consists of a network of the lead-calcium (Pb_3Ca) compound dispersed

Hardness and Tensile Strength

Testing Temp. °C.	Testing Temp. °F.	Brinell Hardness (250-kg. load, 10-mm. ball)	Tensile Tests on 0.505-In. Cast Bars Ultimate Strength	Elongation
26	78	21.5	11,070 psi.	5.8%
65	149	19.2	9,210	7.3
00	212	17.0	7,380	7.3
50	302	11.0	4,890	13.1
80	356	9.0		
00	392	7.7	2,820	16.9

Compressive Strength

Specimens 0.5 in. diameter by 1 in. high
Rate of compression 0.04 in. per min.

Testing Temp. °C.	Testing Temp. °F.	Stress (Psi.) at Indicated Deformation 1%	2%	4%	6%	8%	10%
26	78	10,850	12,150	13,100	13,700	14,150	14,550
65	149	9,700	10,400	10,850	11,200	11,500	11,700
00	212	7,000	7,400	7,650	7,900	8,100	8,360
50	302	4,950	5,350	5,650	5,850	6,000	6,150
00	392	3,280	3,420	3,520	3,590	3,620	3,650

throughout a ground mass of tin and calcium in solid solution in lead. This type of structure conforms to the usual structure of bearing metals, which consists of hard crystals distributed in a softer matrix. Note the micros below.

Strength at High Temperatures

Pouring temperature for these lead bearings should be in the neighborhood of 1050° F. (the liquidus is 788° F. and solidus 563° F.). Hardness, tensile strength and loads to produce definite deformation at various temperatures are given in the table on page 63.

Since the initial melting point of this alloy is approximately 100° F. higher than that of the regular tin and lead base babbitts, there is much less probability of the metal melting and running out if the bearing becomes overheated. At 400° F., a temperature which may be reached in gas engines, it still retains adequate hardness and strength to function as a bearing; its elongation, while not high, is sufficient to allow the metal to conform to the shaft. Due to its considerably greater compressive strength at elevated temperatures than either of the usual tin base or lead base babbitts, it would not be squeezed out under moderately heavy loads. In compressive tests wherein the deformation was carried to 25%, no cracking of the metal was observed. It has been demonstrated that the thinner the bearing metal is in a lining, the greater is its resistance to compression. As the bearing linings in use today are relatively thin, some having a thickness as low as a few hundredths of an inch, the stress required to deform the bearing lining will be materially greater than that shown in the table for test specimens of comparatively large size.

No difficulty is experienced in bonding it to steel or bronze backs; no dovetail grooves or other mechanical means of anchorage are necessary. Tensile tests of butt end joints made by casting showed a strength of 8000 to 8500 psi. (compare with the strength of 11,000 shown in the table).

No great difficulty is experienced in the melting and casting of Satco metal. A good average pouring temperature is 1050° F. Just before pouring, the metal should be stirred well (but not continually during the melting operation as this causes drossing). Tests have shown that after repeated meltings, no loss of the hardening elements had taken place.

(Continued on page 72)

Microstructure at 100 and 500 Diameters Respectively Shows Hard Calcium-Lead Crystals in Ground Mass (of Tin and Calcium in Solid Solution or Finest Dispersion of Lead)

Letters to the Editor

Dr. Sauveur's Views on the Microstructure of Steel

CAMBRIDGE, MASS. — I read with much interest the symposium on "Components of Steel; Austenite, Martensite, Pearlite, Sorbite" in METAL PROGRESS for August. Will you permit me to express some thoughts on that subject as they have gradually crystallized in my mind after many years of active participation in discussions and laboratory investigations?

I do not think that martensite, troostite, sorbite and pearlite should be described as components or constituents. In alloys of iron and carbon the phases only are the constituents, three in number, namely austenite, cementite and ferrite (Howe's "metarals"). The so-called "transition constituents" martensite, troostite and sorbite are *aggregates representing different degrees of agglomeration of the carbide particles.*

In martensite the cementite particles are of minimum size, probably submicroscopic, imparting maximum hardness and strength to the alloy consistent with its carbon content. This results from the allotropic transformation of the solvent from the gamma condition (capable of dissolving as much as 1.7% carbon) into alpha iron, practically unable to retain any carbon. So excessive a degree of supersaturation must necessarily be followed by *immediate* precipitation of the solute. We should look upon martensite, therefore, as a completely or nearly completely aged aggregate.

In troostite and sorbite agglomeration of the carbide particles has taken place resulting in decreased hardness and strength. These so-called "constituents" (in reality aggregates) really represent different degrees of carbide agglomeration, and it is evident that no sharp line of demarcation can be drawn between them. Agglomeration is a continuous and progressive phenomenon. A more pronounced degree of agglomeration results in the structural condition generally referred to as "spheroidized" pearlite, and it is doubtful if any would venture to draw a line between sorbite and spheroidized pearlite. Both, let it be repeated, are *structural conditions* representing different degrees or forms of carbide agglomeration. Any attempt at drawing rigorous definitions of these aggregates appears to me futile.

Regardless of any treatment, thermal or mechanical, to which an alloy of iron and carbon may have been subjected, it will always consist of two constituents only (which it might be better to call "phases"), namely, ferrite and cementite and nothing else — leaving out of consideration the retained austenite which may be present in some quenched steels. The many different sets of physical properties it is possible to impart to any given iron-carbon alloy by treatment, thermal or mechanical, results solely from the grain size of ferrite and the particle size of its carbide.

For any given carbon content the smaller the particle size of the cementite, the greater the hardness and strength and the less the ductility, and, likewise, the smaller the grain size of the ferrite, the greater the hardness and strength and the smaller the ductility.

Increase of hardness and strength resulting from cold working is due to the fragmentation of ferrite grains — that is, conversion of large ferrite grains into very small grains — from which it follows that to harden by cold working the more ferrite the better; that is, the lower the carbon the better. To harden by heat treatment, on the contrary, the more carbon the better.

It will be apparent that I am disregarding in this discussion the possible influence of impurities on the physical properties of steel.

The reader may note that the views now offered are not in full agreement with opinions previously expressed by the author. The author readily admits it and does not think that he should attempt to justify it. He believes that any one engaged in scientific research or study should be prepared to discard without hesitation any view he may have held whenever a theory more plausible, simpler or better supported by experimental evidence is offered to him, or conceived by him.

So simple a picture of the constitution of alloys of iron and carbon and of the rationale of their thermal and mechanical treatments may be, it is feared, rejected by those who believe that a simple explanation proceeds from a simple mind, whereas a complex and confused conception reveals profundity of thought. I believe, however, that the laws of nature are always simple and that their apparent complexity at times is of our own making.

ALBERT SAUVEUR

Largest All-Welded Ship

LONDON, ENGLAND — Your September issue contains a very timely article by F. Grimshaw Martin pointing out that the service records of welded ships are excellent. The first all-welded ship, the 150-ft. Fullagar, certainly has had more than its share of vicissitudes. A view at top of right hand page shows damage done in a head-on collision (the ship is renamed for a second time and is now the Shean) where again the toughness of the welds is amply demonstrated. It may be seen that the shell plating has joggled lap joints.

One might infer from Mr. Martin's article that the 150 to 160-ft. ships described by him are the largest yet to be constructed. As a matter of fact, a motor vessel Joseph Medill just built by Swan, Hunter and Wigham Richardson is believed to be the largest all-welded ship. Her dimensions are length over all 259 ft., breadth molded at deck 43 ft. 10 in., depth molded 22 ft., 14 ft. draft when carrying 3100 tons of freight. This ship is to go to Canada under its own power, and will be put into service on the Great Lakes for carrying pulp wood, newsprint and grain.

This ship is but a little longer than an all-welded oil tanker 245 ft. long, built to Lloyds Register 100 A1 class earlier in the year by the same British firm. It was christened Moira, and is now in ocean-going service for her owners, Dampskibsselskabet Marna of Oslo, Norway. All obstructions have been eliminated inside the five main tanks, the smooth surfaces of which allow easy drainage and cleaning. Transverse and centerline bulkheads are a series of trough plates, welded together, thus dispensing with all projecting stiffeners. Shell plating is butt welded with the exception of the joint at the bilge, which is lapped on to the side plating so it can be welded in the down position.

WALTER E. QUINE
Naval Architect
The Quasi-Arc Co., Ltd.

[EDITOR'S NOTE: — Quebec & Ontario Transportation Co., Ltd., of Montreal, write that the motor ship Joseph Medill is a month overdue, and it is believed it foundered in one of the hurricanes which prevailed on the Atlantic during the voyage. No wreckage has been picked up and some hope is still held, as the ship was not equipped with wireless, it being intended for the Lakes trade. If the worst has happened on the maiden voyage, a great deal will be said about the behavior of welded ships in heavy weather!]

259-Ft., 3100-Ton Motor Vessel Joseph Medill, All-Welded, Built in 1935 for Great Lakes Service

Collision Damage to All-Welded Motor Vessel Fullagar (Now the Shean) Wherein Properly Made Welds Again Demonstrated Their Strength and Toughness

Heat Resisting Cast Irons

PARIS, FRANCE — The remarkable chemical resistance of steels to hot gases (especially hot oxidizing gases) achieved by adding elements such as chromium, silicon, and aluminum is due to the formation of a protective film at the surface. Success in this direction ought naturally to lead to the application of the same principles to cast iron, in order to increase its resistance to hot oxidation and at the same time to obtain cheaper materials, easier to cast than highly alloyed steels.

However, the problem is more complex because there are some other causes of destruction during heating, not present in steel. Such causes may be summarized under three principal heads:

1. Graphitization or decomposition of the iron carbide with concurrent expansion.

2. Unequal expansion which forms internal cracks, more particularly when the variations in volume accompany the transformations of the various micro-constituents.

3. Corrosion, oxidation or sulphurization by hot gases, steam and suspended dusts, is not only an external corrosion, but also an internal one, because of penetration into expansion cracks and into graphitic flakes.

In order to withstand these three, the following means may be employed:

1. Suppressing graphitization by some alloying additions which either stabilize the iron carbide (such as additions of Cr, Mn, W, Mo or V which form "carbide cast irons") or, on the contrary, completely decompose the carbide or produce graphite on solidification (such as additions of Si, Ti or Ni to form "graphite cast irons").

2. Eliminating any transformations in the temperature to be met in service, by limiting the total carbon and adding sufficient proportions of either Al, Si or Cr (extending the alpha state of iron and thus forming ferritic castings) or of Ni or Mn (which depress the normal critical range and extend the gamma state of iron and thus form austenitic castings).

3. Improving the resistance to oxidation and sulphurization by adding such elements as produce protective and adhesive films (such as Cr, Al, Si and Zr) and avoiding elements which permit intergranular attack (for instance, nickel in sulphurous atmospheres). In order to prevent gaseous penetration the graphite must exist in finely divided, discontinuous particles.

From the above considerations it follows that two classes of cast iron will probably be resistant to chemical reaction of hot furnace gases, and experiment and experience bears out these conclusions:

1. Chromium cast irons. Chromium may be present up to 35 or 40%, producing either ferritic or carbide cast irons depending on the mutual relationships of chromium and carbon. Silicon, aluminum and zirconium may be added to further improve their oxidation resistance; nitrogen refines the grain, as cast, and improves toughness. These matters are discussed in various chapters of The Book of Stainless Steels, and in a paper by Garnet Phillips before the American Foundrymen's Association, 1934.

2. Silicon cast iron, aluminum cast iron and silicon-aluminum cast iron. These are ferritic and graphitic in structure, and are described in an important communication to the British Iron and Steel Institute, 1934, by Prof. H. Thyssen, director of the Liége research committee into the behavior of metals at high temperatures. This paper should be consulted for its wealth of detail.

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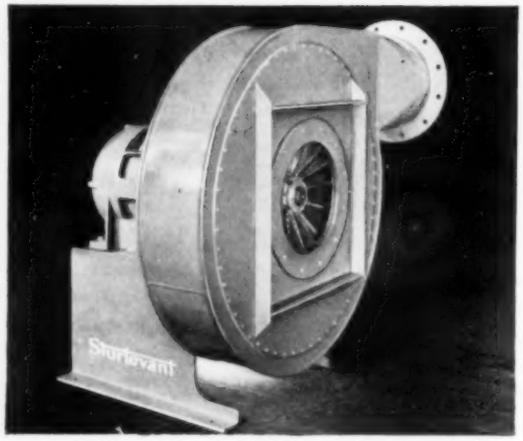

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Previous researches into the properties of cast irons in the last category have produced some discordant results, which now appear to be due to the fineness, continuity and amount of graphite existing in the alloy, all these characteristics varying according to whether the iron is hypo-eutectic or hyper-eutectic. In fact this dividing line is of great importance but fortunately can be simply determined by the castability of the alloy (see METAL PROGRESS for May, 1932). The composition of the eutectic alloys in the iron-silicon-carbon system, for instance, as determined by thermal analysis by Dr. Poboril check the values obtained by Prof. Thyssen in the foundry by its castability.

The chemical analysis of the silicon cast iron that has the best combination of properties is found to be 5.5% Si, 2.5% total carbon, slightly hypo-eutectic. It is moderately strong in bending and fairly tough in impact, higher silicon irons being deficient in this respect. The 5.5% silicon cast iron is soft and machinable (Brinell 190), strongly resistant to hot air at 1750° F., but in contact with fine silica sand corrodes considerably.

Parallel tests showed that aluminum also gives the iron good resistance to corrosion at high temperatures, the same proportions giving very nearly the same results. However the mechanical properties are seriously impaired and Prof. Thyssen determined to investigate what seemed to be the best combination of aluminum and silicon in the alloy.

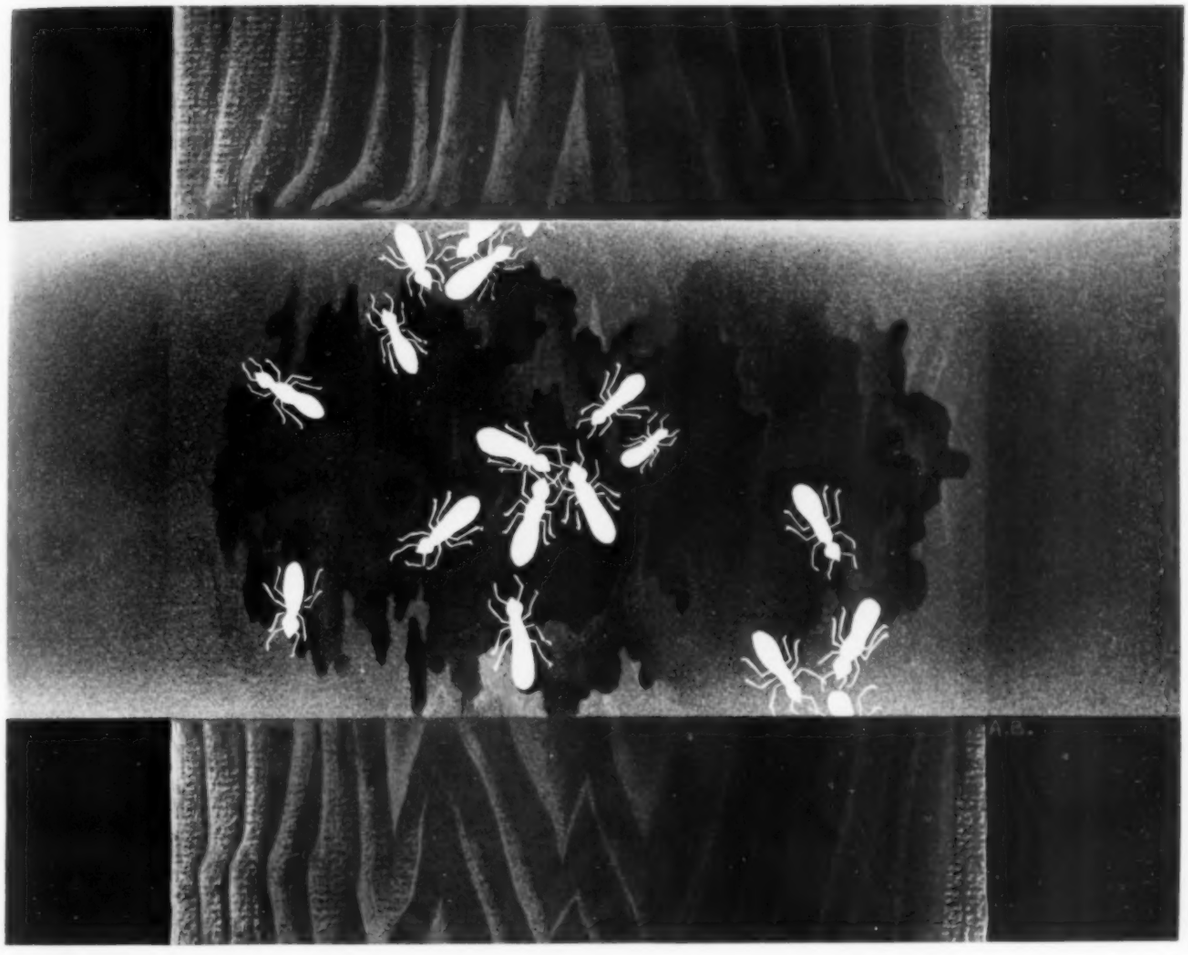
Best resistance to hot oxygen, sulphur and dust was had with a slightly hypo-eutectoid alloy containing 6.5 to 7.0% aluminum, 5.0 to 6.0% silicon and 1.80 to 1.90% carbon (a narrow range, difficult to hit in the foundry). These irons are ferritic with fine graphite, but hard spots readily form in green sand castings or thin sections.

Unfortunately these analyses leave something to be desired as to mechanical properties and foundry characteristics. In order to improve the mechanical properties at high temperature, one may have recourse to austenitic cast irons by addition of nickel, with or without copper, but this addition tends to decrease the chemical resistance, more particularly in sulphurized gases.

ALBERT PORTEVIN

Correction to page 37

Correct 26th line from end to read 9° F. per min. (Printer's error).



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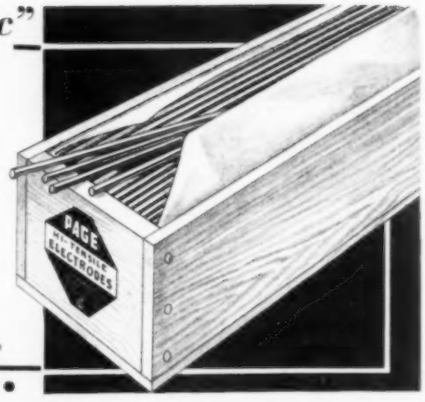

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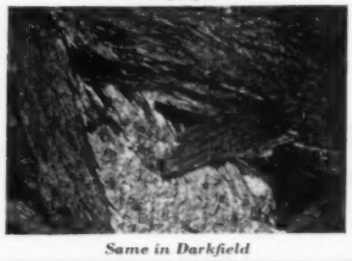

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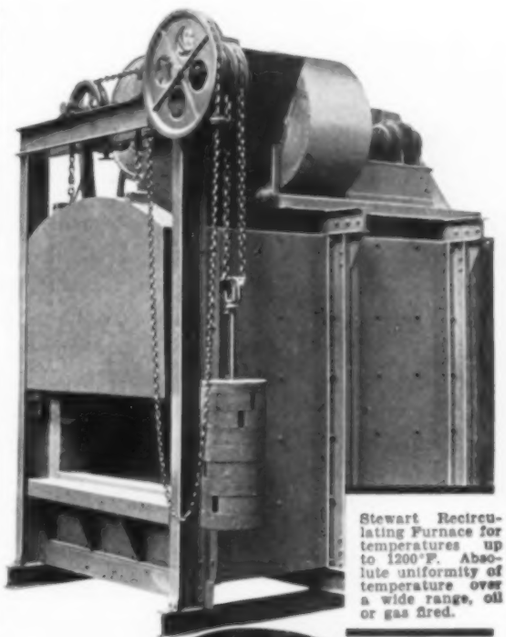

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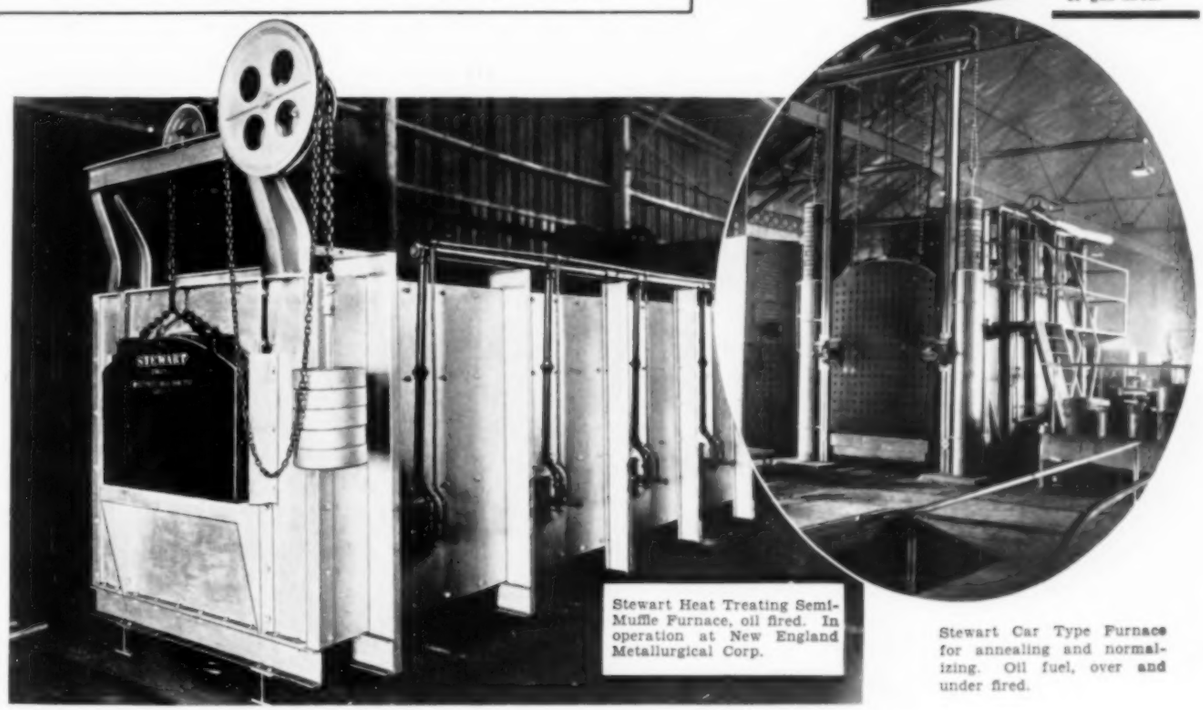

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New Bearing Metal

In casting on to metal backs, the backs should be first tinned, using "Satco flux and bonding metal." Then with the bonding metal on the backs in the molten or semi-molten state, the alloy is cast on. Either hand pouring or centrifugal casting may be used.

Favorable laboratory tests are substantiated by reports from service. It is interesting to note the experience of one of the western railroads with this bearing metal in gas-electric cars. These cars are subjected to severe service conditions, making in the neighborhood of 10,000 miles per month in passenger service. The engines are run at excessively high speeds part of the time and the rest of the time are either idling or running at low speeds. There is considerable torque on the crankshafts due to the design of this particular diesel engine.

Service More Than Doubled

The first tests with Satco-lined connecting rod bearings were made late in 1933. The results were so satisfactory that the road decided to equip all its motor cars with this alloy. Prior to the tests, the best that railroad had been able to get from tin-base babbitt linings was around 40,000 miles, and the best with lead-bronze linings from 20,000 to 30,000 miles. Bearings failed by cracking of the lining or scoring of the shaft. A set of bearings on connecting rods lined with this new alloy was examined after 60,000 miles of service and the tool marks were still visible, indicating practically no wear, and this same set is still running after 200,000 miles. Bearings are now expected to operate satisfactorily for at least 90,000 miles or an equivalent of 3000 hr. of service, whereas the maximum for ordinary babbitts was about 45,000 miles or an equivalent of 1500 hr. of service.

Karelitz and Ellis find that the "wiping" temperature of Satco bearings is close to the solidus (563° F.) which emphasizes the high temperature the metal can endure without failure. Leland E. Grant, chief chemist of Chicago, Milwaukee, St. Paul & Pacific R. R., has stated that this is probably one of the most important features that make the metal valuable for railroad service, for it will withstand temporary local overheating without much harm being done.

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When you Stretch a Rubber Band

What Happens?

Much the same as happens when plastic metal contracts against a sand core. Both are highly stressed in tension, and both may break. But, if the core in a casting is eliminated, contraction may proceed unrestrained. Cooling strains are avoided, wall sections can be made much lighter, yet stronger. Misco "Centricast" Products are made without cores. THE LIGHTEST WALL SECTIONS ARE SOUND. That is one reason why Misco "Centricast" Products will serve you better.

Misco centrifugal castings are recommended for: Conveyor rolls for sheet normalizing furnaces, bright annealing and heat treating furnaces . . . Rollers for all types of conveyors . . . Glass rolls . . . Tube rolls for paper machines . . . Chemical piping: flanged, threaded, plain . . . Press rolls . . . Carburizing and annealing boxes . . . Radiant heater tubes . . . Burner pipes . . . Hollow Shafting . . . Blowpipes . . . Hinges of all kinds . . . Bushings . . . Valve seats . . . Cylinder liners

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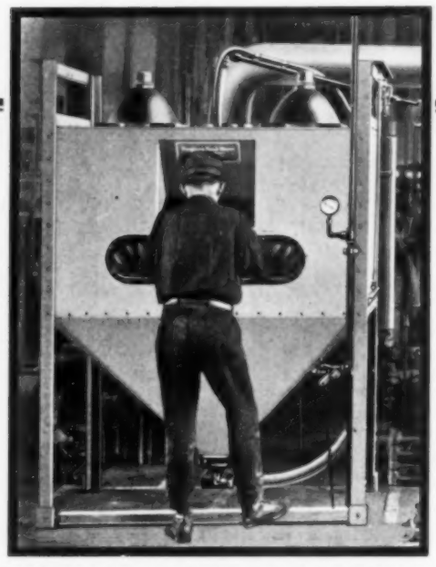

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Write this on your Calendar NOW!

I. A. A. Convention in Cleveland Nov. 12-13-14-15

● The Thirty-Sixth Annual Convention of the International Acetylene Association will be held in Cleveland, November 12, 13, 14, and 15 at the Hotel Cleveland.

This meeting will mark another important milestone in the development and progress of the I.A.A. For the first time in its history, this Association, which is one of the oldest active technical societies in the country, will meet in this great industrial center.

This year's Convention promises to be bigger and better than ever. (Last year's broke all previous records.) You cannot afford to miss it. If you attend you will get, first-hand, the information on recent oxy-acetylene developments that you need to keep up with the welding and cutting demands of today.

A few of the important papers are listed here. These subjects and many others will be discussed by nationally-known authorities. Come, bring your problems, and let the other fellow's experience help you solve them. Get new ideas that you can use to advantage during the coming year.

Plan now to be there. Write to the Secretary at once for a copy of the complete program as soon as it is off the press.

Some of the Topics for Discussion at the 1935 Convention

- Welding and Cutting of High Tensile Medium Alloy Steels
- Studies of Oxy-Acetylene Cut Steel Plate
- Hydrocarbon Fuel Gases for Cutting
- High Pressure Piping
- Welding Class I Pressure Vessels
- Maintenance of Way Problems in High Speed Transportation
- Shape Cutting of Locomotive and Car Parts
- Gas Welding of Aluminum and Its Alloys
- Chemical Uses of Acetylene
- Safety in the Oxy-Acetylene Industry
- Prevention of Fires
- Safe Handling, Storage, and Return of Compressed Gas Containers

36th

Annual Convention

•

Hotel Cleveland

Cleveland, Ohio

•

November 12, 13, 14 and 15, 1935

INTERNATIONAL

Acetylene Association

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showed that diametrical viewpoints can be found in the literature concerning nearly every aspect of temper brittleness, and argued that a laboratory test for "susceptibility" should not be used to condemn or exclude the use of metals from a given service. He cited the satisfactory experience with plain carbon steels operating in power stations at 550 to 750° F., which is the very "blue-brittle" range where laboratory tests would show them to be dangerous. He also pointed out that many thousands of tubes and valve castings of 4 to 6% chromium with 1% tungsten were giving satisfaction in oil refinery service, and despite the fact that the "susceptibility" ratio in Mr. Wilten's tests was more than one. He quoted Mr. Wilten's own figures in another publication which gave this alloy, even when furnace cooled, a higher impact value than other "non-susceptible" steels.

Speculations as to the cause of temper brittleness were also indulged in. Mr. Wilten believes it is caused by different things than aging, for plain carbon steel which ages is not temper brittle, nor is it associated with intergranular corrosion, for such is absent — but is rather one of the reversible phenomena associated with change in toughness with temperature. Mr. Newell, however, favors the theory that submicroscopic precipitation at grain boundaries is responsible, and suggests that fine grained material is much less susceptible than coarse grained. Hence the efficacy of the grain-refining effect of molybdenum. (P. Payson, metallurgist, Crucible Steel Co., agreed with Mr. Newell that certain microstructures are unlikely to be temper brittle, but believes that spheroidized cementite would give tougher steels after long heating than companion pieces which were pearlitic at the start.) Mr. Malcolm finds that chromium steels solidify with a network, presumably high chromium ferrite, having extra solubility for carbon, and presumably it is the changes in this ferrite which are responsible for temper brittleness. For the 5% chromium, 1% tungsten steels he recommends a soaking anneal slightly below the transformation point to diffuse the elements out of the network, as far as may be possible, followed by a quench from just above the transformation to recrystallize the metal. Steels so treated he claims will be tough no matter how they are cooled.

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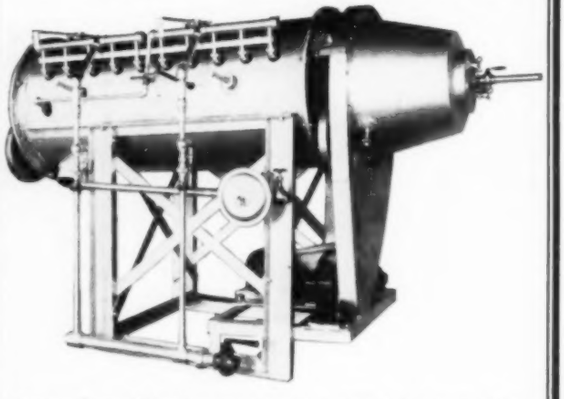

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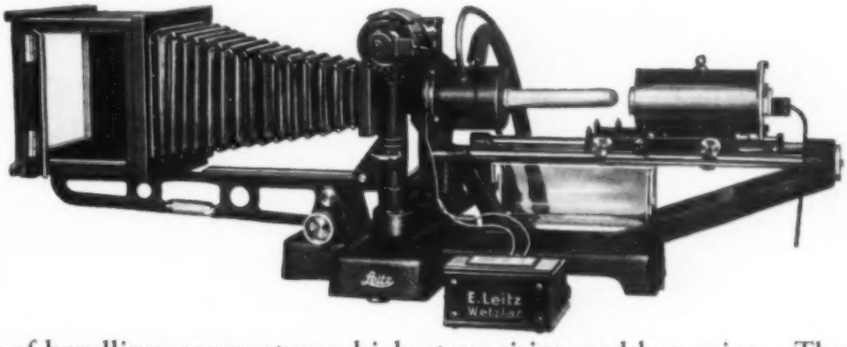

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Aluminum in Steel

(Continued from page 37)

Since aluminum promotes coarser carbide particles in the ferrite, an austenite with aluminum in solution must be cooled more rapidly to produce that finest carbide distribution known as martensite — or even a fine pearlite structure. The tendency to coalesce the carbides and form thereby a coarser pearlitic structure would be overcome by such additions as manganese and nickel which would lower the austenite transformation rate to the point where the rigidity of the ferrite interferes with carbide coalescence. Thus it would be possible, by the addition of manganese, to obtain with ordinary quenching the necessary hardness in a steel containing aluminum. On heating this steel, however, coalescence would occur on approaching the temperature of transformation, and the heavier carbide particles would, as before, tend to inhibit grain growth so that with the high manganese steels we get the benefit of the deeper hardening properties and at the same time the fine grain structures which are characteristic of those steels containing aluminum.

The addition of any of the deeper hardening elements to steel containing aluminum would produce a result similar to that of manganese, so that the benefits of the aluminum addition to the alloy steels would still be worth while.

It is not intended to claim at this time that the grain growth characteristics, the hardenability characteristics or the abnormality characteristics are due to either the presence of submicroscopic alumina particles or to the effect of aluminum on the austenite transformation rate and rate of carbide rejection. The explanation that aluminum influences the hardenability and grain growth characteristics by its effect on the coalescence of the carbides precipitated when the austenite transforms is simply offered as a theory which seems to have a somewhat closer agreement to practice than would seem to be the case if we tried to explain these phenomena on the basis of submicroscopic alumina dispersion.

It is offered simply as a suggestion and only as a theory in the hope that it might lead to a more general discussion and investigation of the behavior of aluminum when added in relatively small quantities to commercial heats of steel.

CHROME-MOLYBDENUM STEEL

Steel containing Chromium, Manganese, Silicon and Molybdenum, and having a tensile strength of approximately 75,000 lbs. per sq. in., is one of the newer alloys. It is used where great creep strength at high temperatures is desired.

MUREX CHROME-MOLYBDENUM

WELD METAL

PHYSICAL PROPERTIES

Tensile Strength	75,000 to 80,000 p.s.i.
Yield Point	55,000 to 60,000 p.s.i.
Elongation in 2 in.	25% to 28%

CHEMICAL ANALYSIS

Chromium	.32%	Carbon	.085% to .09%
Molybdenum	.085%		

Murex Chrome-Molybdenum Electrodes are used widely in the fabrication of petroleum refinery equipment and modern high pressure boilers designed to operate at 850° to 1000° F.

Rapid in operation and having excellent welding qualities, they can be depended on to produce sound clean welds consistently. The physical properties of these deposits are equal in every respect to those of the parent metal.

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Convection Heating

(Continued from p. 60) classed as "remote heating," in that the fuel is burned in a separate combustion chamber isolated from the main furnace or oven and only the circulating gases are delivered to the furnace or oven. Its commercial development has also involved the design of a complete line of heaters, both large and small. Some of these heaters are so large as to burn nearly 100 gal. of oil per hr.

For small installations the heater, container and circulating device may conveniently be built as an assembled unit. Such a device has many useful applications and is extremely compact. The unit photographed on page 60 operates normally at temperatures up to 1200° F. and tempers 400 to 500 lb. of closely packed metal parts at one loading. The uniformity is so great that individual inspection may be omitted, which in itself represents a considerable saving in cost.

Summary of Advantages

It would therefore appear, as a result of a rather extended experience on both ferrous and non-ferrous metals as well as other materials, that forced convection offers the following definite advantages over other commercial methods of transferring heat:

1. The economy is very great, reducing fuel cost to a minimum.
2. The quality of the material is within close control.
3. The grain size and degree of hardness are unusually uniform.
4. The operation is substantially automatic, thus frequently eliminating the necessity for detailed inspection.
5. The rate of heat application is more rapid than in most other methods.
6. The equipment is relatively inexpensive and very flexible.